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CHARACTERIZATION, RISK ASSESSMENT,
AND REMEDIAL ACTION PLAN
FOR VOLATILE ORGANIC CONTAMINATION
AT THE TRW SITE IN MINERVA, OHIO

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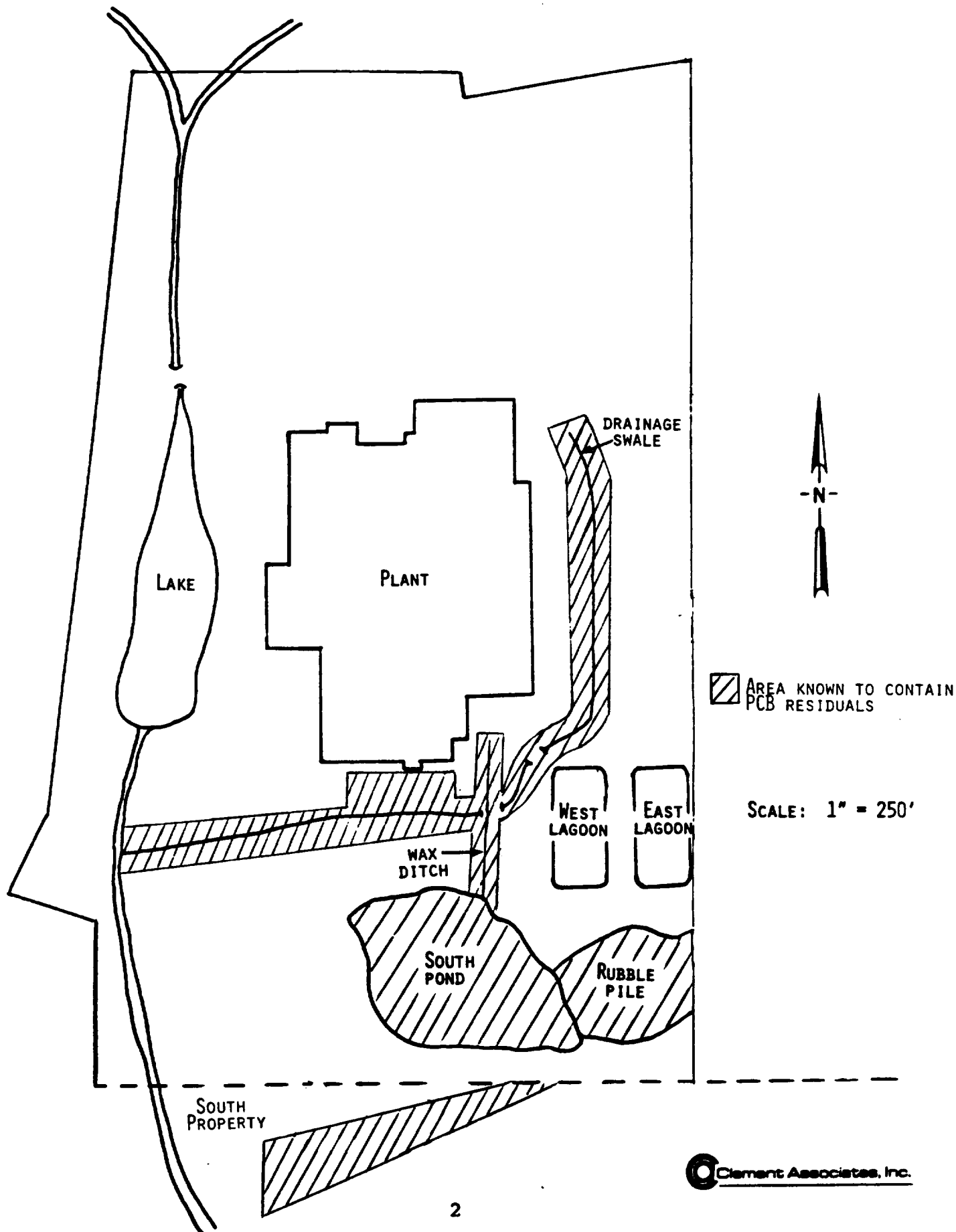
I. BACKGROUND

In August 1981, TRW, Inc. notified the U.S. Environmental Protection Agency (USEPA) and the Ohio Environmental Protection Agency (Ohio EPA) that polychlorinated biphenyls (PCBs) had been detected in soils at TRW's plant in Minerva, Ohio. Following this discovery, TRW retained Clement Associates to conduct a thorough assessment of the extent and distribution of PCBs at the site, evaluate the potential for off-site movement of PCBs, assess the potential health and environmental risks posed by the presence of PCBs at the site, and provide guidance in selecting appropriate remedial measures. During this investigation, PCB residuals were detected in several areas at the Minerva site. These areas, depicted in Figure 1, include a drainage swale located adjacent to a former drum storage area on the east side of the plant, a large pond (South Pond) that received a variety of plant effluents in the past, a ditch (the wax ditch) that was used to transport casting wax to South Pond, and a rubble pile containing a variety of construction debris and waxy residues. Additionally, a narrow strip of land on the South property¹ located south of the plant, exhibited surficial PCB contamination.

Although results of a risk assessment showed that the levels of PCBs found at the plant pose a negligible risk to public health and the environment, TRW presented to the

¹Originally the Fry property, this parcel of land was purchased by TRW in 1982 for the purpose of installing monitoring wells.

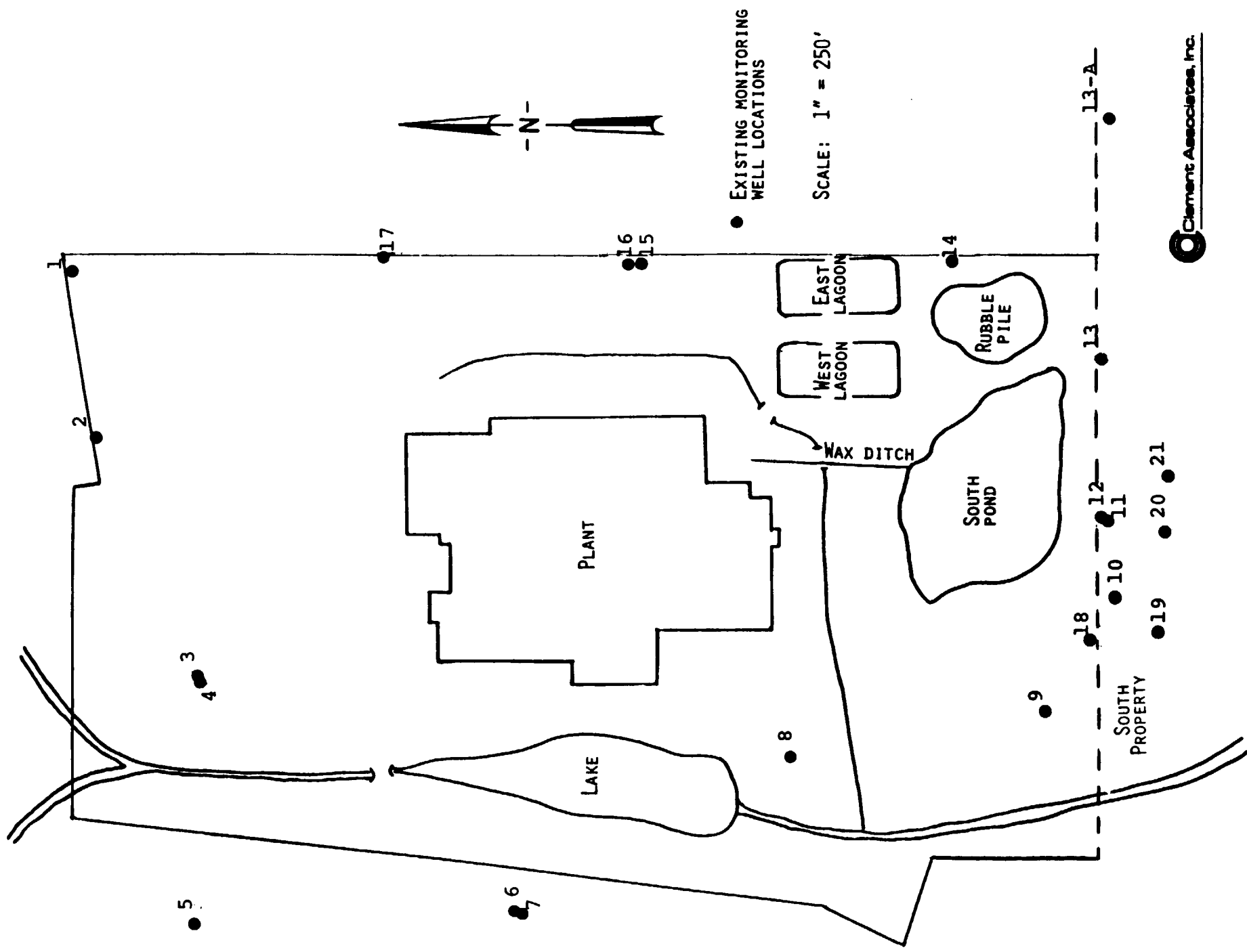
FIGURE 1
AREAS OF KNOWN PCB CONTAMINATION
AT THE TRW MINERVA SITE



state and federal EPA on June 20, 1983 a preliminary plan to uniformly reduce such risks to insignificant levels. Both the USEPA and the Ohio EPA, respectively, responded to TRW's presentation with written requests for further information (August 9, 1983 and July 28, 1983), including a request for detailed engineering plans of proposed site remediation. A revised report was subsequently submitted to the USEPA and Ohio EPA on December 20, 1983, and is currently being reviewed by those agencies.

In the spring of 1984, a concern was raised that other organic compounds might be present at the Minerva site. An earlier study of such compounds, presented in the June 20, 1983 report, consisted of a gross scan designed to detect the presence of other organic compounds at concentrations sufficient to affect the transport of PCBs at the site. Although results of the gross scan were negative, they did not eliminate the possibility that such compounds might be present at lower concentrations. To check for this possibility, complete volatile organic scans were performed on groundwater samples collected from selected monitoring wells (Nos. 2, 10, 12, 13, 14, and 19) at the Minerva site. Locations of monitoring wells installed at the Minerva site are presented in Figure 2. Initial testing of these six wells on June 1, 1984 showed that three of them (Nos. 10, 14, and 19) exhibited detectable quantities of between 1 and 3 of the 30 compounds normally evaluated in a complete

FIGURE 2
EXISTING MONITORING WELL LOCATIONS
AT THE TRW MINERVA SITE



volatile organic scan.¹ All other results were negative. Compounds detected in the three wells at concentrations exceeding the 10 parts per billion (ppb) detection limit were trichloroethene (trichloroethylene (TCE)) in wells 10 and 19, 1,1-dichloroethane in wells 10 and 19, and trans-1,2-dichloroethene in wells 10, 14, and 19. Results of these analyses are presented in Table 1 under the June 1, 1984 sampling date heading. Subsequent groundwater analyses, also presented in Table 1, are described later in the text.

Motivated by the detection of these three new chlorinated organic compounds in groundwater at the Minerva site, TRW requested that Clement Associates evaluate the significance of these results. As a first step toward accomplishing this task, a preliminary study was initiated on June 12, 1984 to define the scope of the problem which would be addressed in a detailed study conducted later. Results of the preliminary study were reported in June and are discussed below. Results of the detailed study were reported in July and August and are discussed in Section II of this report.

The purpose of the preliminary study was to confirm the occurrence of volatile organics exhibited in the groundwater

¹Volatile organics were sampled and analysed in accordance with methods 8010, 8015, and 8020 of EPA's "Test Methods for Evaluating Solid Waste" (SW-846, July 1982). Because of the nature of the procedures involved, a complete volatile organic scan will actually detect the presence of 60-70 organic compounds, only 30 of which are currently of concern to USEPA (Dr. Marvin Stephens, Alert Laboratories, personal communication 1984)

TABLE 1

RESULTS OF VOLATILE ORGANIC ANALYSIS OF GROUNDWATER SAMPLES FROM THE TRN SITE, MINERVA OHIO¹
(Concentrations in $\mu\text{g/liter}$)

ppb

Compound	Well No. 1				Well No. 2				Well No. 8				Well No. 9				Well No. 10				Well No. 11				Well No. 12			
	a	b	c	d ²	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d ³	a	b	c	d	a	b	c	d ²
1,1,1-Trichloroethane	NS	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	30	26	18	-	11	-	-	NS	-	-	-	-	-	-	-
1,1-Dichloroethane	NS	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	22	17	17	47	200	260	290	NS	26	63	71	-	-	-	-
1,2-Dichloroethane	NS	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-	-	-	-	-	-	NS	-	-	-	-	-	-	-
Chloroethane	NS	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-	-	-	-	-	-	NS	-	-	-	-	-	-	-
Trichloroethene	NS	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-	-	39	120	100	140	NS	12	18	23	-	-	-	-
1,1-Dichloroethene	NS	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-	-	-	-	-	-	NS	-	-	-	-	-	-	-
Trans-1,2-dichloroethene	NS	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-	-	120	320	350	500	NS	45	96	150	-	10	114	73
Chloroethene	NS	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-	-	-	-	-	-	NS	-	-	-	-	-	-	-
2-Propanone	NS	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-	-	-	-	-	-	NS	26	-	-	-	-	-	-

¹ Although a complete volatile organic scan was performed on all samples listed, only positive results are presented in this table. Compounds normally reported in a volatile organic scan but not listed in this table were not detected.

² Butyl acetate was detected in addition to the listed chemicals. In well 12 the concentration of butyl acetate was sufficient to interfere with other analyses resulting in a detection limit of 500 ppb.

³ Because of the concentrations of volatile organics detected in well 10, the limit of detection had to be raised to 50 ppb.

⁴ In addition to the listed chemicals, tetrachloroethene was found at 48 ppb.

Key:

- = Compound not detected

T = Trace compound detected at concentration below the stated 10 ppb detection limit

NS = Well not sampled on date indicated

Sampling dates: a-June 1, 1984; b-June 12, 1984; c-June 28, 1984; d-July 12, 1984

TABLE 1, Continued

Compound	Well No. 13				Well No. 14				Well No. 18				Well No. 19				Well No. 20				Well No. 21			
	Sampling Date				Sampling Date				Sampling Date				Sampling Date				Sampling Date				Sampling Date			
	a	b	c	d ²	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d ²
1,1,1-Trichloroethane	-	NS	12	7	-	NS	-	7	NS	7	-	-	-	7	-	-	NS	-	-	-	NS	-	-	-
1,1-Dichloroethane	-	NS	530	330	-	NS	-	-	NS	108	120	92	12	1,500	1,200	1,300	NS	-	-	-	NS	7	-	-
1,2-Dichloroethane	-	NS	-	-	-	NS	-	-	NS	7	-	-	-	10	-	-	NS	7	7	12	NS	7	-	-
Chloroethane	-	NS	58	43	-	NS	-	-	NS	110	250	270	-	-	-	-	NS	-	-	45	NS	-	-	-
Trichloroethene	-	NS	18	7	-	NS	15	11	NS	7	-	-	13	1,300	1,300	1,200	NS	-	-	-	NS	7	-	-
1,1-Dichloroethene	-	NS	-	-	-	NS	-	-	NS	-	-	-	-	25	-	16	NS	-	-	-	NS	7	-	-
Trans-1,2-dichloroethene	-	NS	120	-	30	NS	14	18	NS	11	-	12	32	910	690	1,300	NS	15	12	27	NS	45	7	18
Chloroethane	-	NS	-	-	-	NS	-	-	NS	-	-	-	-	91	-	110	NS	-	-	-	NS	-	-	-
2-Propanone	X	NS	-	-	-	NS	-	-	NS	-	-	-	-	-	-	-	NS	-	-	-	NS	-	-	-

analyses reported on June 1, 1984 and provide an indication of the potential sources of such materials at the site. Thus, volatile organic scans were performed on fresh groundwater samples from site monitoring wells and on a small number of samples collected from known sources of PCBs at the site (including the swale, the wax ditch, and South Pond). Additionally, information was developed concerning the historical use of such materials at the facility. Results of groundwater analyses from this preliminary study are reported in Table 1 (under the June 12, 1984 heading), and soil/sediment analyses are presented in Table 2.

Results of the June 12th study confirmed that groundwater samples taken from several downgradient wells at the site exhibit detectable concentrations of a number of volatile organic compounds. The compounds detected include 1,1,1-trichloroethane (TCA), trichloroethene (TCE); 1,1-dichloroethane; 1,2-dichloroethane; 1,1-dichloroethene; and trans-1,2-dichloroethene. Traces (concentrations below the reported limit of detection of 10 ppb) of 2-propanone (acetone), chloroethane, and chloroethene (vinyl chloride) were also detected.¹ However, because of scatter in the data, the actual concentrations of these compounds and the significance of their relative distributions could not be determined without further investigation. Accordingly,

¹Of the 60-70 compounds potentially detected in a complete volatile organic scan, these nine were the only ones detected.

TABLE 2
RESULTS OF SOIL AND SEDIMENT SAMPLE ANALYSES
FROM A PRELIMINARY STUDY OF VOLATILE ORGANIC
COMPOUNDS AT THE TRW MINERVA SITE

(June 1984)

Sample Location	Depth	Compounds Detected ^a	Concentration (ppm)
Wax ditch north	6 inches	1,1-Dichloroethane	4.9
		1,1-Dichloroethene	15.0
		Tetrachloroethene	1.7
		Trichloroethene	0.6
		1,1,1-Trichloroethane	800.0
Wax ditch central	6 inches	1,1-Dichloroethane	0.7
		Trichloroethene	0.5
Wax ditch south	6 inches	1,1-Dichloroethane	2.8
		Trans-1,2-dichloroethene	0.9
		1,1,1-Trichloroethane	18.0
Pond east	6 inches	No positive results	
Pond west	6 inches	No positive results	
Swale No. 1	1 foot	No positive results	
	3 feet	No positive results	
Swale No. 2	1 foot	No positive results	
	3 feet	No positive results	
Swale No. 3	1 foot	No positive results	
	3 feet	No positive results	

^aOnly positive results are presented. Limit of detection was
0.2 ppm

additional groundwater data was developed as part of the detailed study discussed in Section II of this report.

Information developed on the past use of volatile organics at the site and results of soil and sediment analyses from the preliminary study indicated that the wax ditch and South Pond are potentially the principal sources of these materials on the TRW property. Information gleaned from inventory records and interviews with plant personnel suggest that between 1957 and 1972 up to 10,000 gallons per year of TCE were used for degreasing and other purposes. In 1972, TCA was substituted for TCE in all plant applications and its use was similar in amount and application to the previous use of TCE. Although the other volatile organics observed in groundwater at the site have never been used at the plant, most of the compounds detected are possible degradation products of TCE and TCA in the environment. These materials, therefore, would be likely to originate from the same sources as TCE and TCA.

Until 1980, when new hazardous waste handling procedures were adopted at the plant, spent degreasing solvents were apparently collected in a portable tank, which was transported to the wax ditch and emptied. Based on the known physical properties of these materials, it is likely that a significant fraction of the material dumped in the wax ditch evaporated. Most of the remaining material probably dissolved in the waxy residues

that were also deposited in the ditch during this period.¹ Concentrations of TCE and TCA also may have been introduced into South Pond when waxy residues flowed down the ditch and mixed with pond sediments. In addition, available information about past plant practices suggests that sediments from the wax ditch and South Pond may have been dredged and deposited periodically in the rubble pile so that the rubble pile represents a third potential source of volatile organic compounds. Based on this information, the wax ditch, South Pond and the rubble pile represent the most probable sources of volatile organics at the site.

Results of soil and sediment analyses from the June 12, 1984 investigation generally support the hypothesis that the wax ditch, South Pond and rubble pile² represent the principal potential sources of volatile organics on the site but are inconclusive because of the limited number of samples collected (see Table 2). None of the six samples collected from the

¹Through additional testing of virgin wax and of waste wax before disposal, TRW confirmed that neither of these was a significant source of volatile organics, and therefore, contamination of waste wax had occurred after its disposal in the wax ditch. Of the three waxes tested (Nos. 701, P20, and Yates 563), only waste P20 wax exhibited detectable levels of volatile organics with a measurement of 4.4 ppm of TCA. Note that six samples were analyzed: one virgin and one waste sample for each wax type. Note also that the limit of detection for these analyses was 2 ppm.

²Because information implicating the rubble pile as a potential source of volatile organics was developed only after the preliminary investigation was complete, rubble pile soils were not tested as part of the June 12 study. However, core sampling in the rubble pile was conducted as part of the later detailed study and results are presented in Section II.

swale at 1-foot and 3-foot depths exhibited any observable concentrations of volatile organic compounds at a detection limit of 0.2 parts per million (ppm). Thus, it is unlikely that the swale is currently a source of volatile organics. In contrast, volatile organics were detected in all three samples of wax ditch residues at concentrations ranging between 0.5 and 800 ppm. In addition, although neither of the two samples of South Pond sediments yielded detectable concentrations of volatile organics, the distribution of waxy residues in pond sediments is known to be irregular so that a larger number of samples would be required to ensure that appropriate deposits are being sampled.

Results of the June 12, 1984 investigation confirmed that samples taken from several downgradient wells at the Minerva site exhibit detectable concentrations of volatile organics and provided an indication that the wax ditch, South Pond, and the rubble pile might represent sources of these materials. Therefore, the scope of the detailed study, conducted in July and August, was to address the significance of the results. Accordingly, the detailed a study was designed to:

- Confirm the sources of volatile organics at the Minerva site
- Assess the impact, if any, that the presence of these compounds may have had on the transport of PCBs at the site
- Evaluate risks to human health and the environment posed by the presence of volatile organics at the site
- Determine what, if any, modifications to the proposed site remediation plan will be necessary to address potential risks from volatile organics at the site

The detailed study had several main components. First, further sampling and analysis was conducted to better characterize potential sources of volatile organics at the Minerva site and the distribution of volatile organics in groundwater. Next, the potential for the migration of volatile organics, the potential for exposure due to migration, and potential health and environmental consequences due to possible exposure were each evaluated as part of a risk assessment. The potential affect that volatile organics may have had on the transport of PCBs at Minerva site was also considered. Finally, the need for modifications to the proposed site remediation plan was evaluated and recommendations were developed. Results and conclusions from each phase of this study are presented in the following sections of this report.

II. CHARACTERIZATION OF VOLATILE ORGANIC CONTAMINATION

Based on the hypothesis that the wax ditch, South Pond and the rubble pile represent the primary sources of volatile organic compounds at the site, a phased sampling and analysis program was initiated as part of a detailed study to better characterize these sources and to define their impact on groundwater at the site. This study, begun on July 11, 1984, was conducted in phases to allow the results of earlier analyses to serve as a basis for targeting subsequent sampling events. In phase 1, a short-term groundwater investigation was conducted to confirm earlier monitoring results, to assist in identification of potential sources of volatile organics at the Minerva site, and to better define the aerial extent of the various volatiles detected in groundwater. Twelve wells (Nos. 1¹, 9, 10, 11, 12, 13, 13a, 14, 18, 19, 20, and 21) were sampled on June 28, 1984 and again on July 12, 1984.² Groundwater samples were then analyzed for volatile organics and the results are presented in Table 1. (12)

To define the extent of residual contamination at potential sources of volatile organics, sediments in the wax ditch and South Pond were sampled in phase 2 of this study. Four cores were collected in the wax ditch at the locations indicated

¹Well 1 serves as an upgradient control.

²It should be noted that the sampling team discovered on June 28th that well 13a could not be sampled because the well casing was deformed and will no longer permit passage of a bailer.

in Figure 3. Each core was then sampled at four depths (the surface, 1 foot, 2 feet, and the underlying clay) and analyzed for volatile organics. Results are presented in Table 3.

Five cores of sediments were also collected from South Pond at the locations indicated in Figure 4. Representative samples were then taken from each core at depths corresponding to the surface, 1 foot, and the underlying clay and analyzed for volatile organics. Results are presented in Table 4.

In phase 3, the distribution of volatile organics in the rubble pile was also examined because these compounds were detected in groundwater downgradient of the rubble pile during phase 1. Eight cores were collected from the rubble pile at the locations depicted in Figure 5 and analyzed at representative depths (1 foot, 2 feet, and 5 feet) for volatile organics. Results are presented in Table 5.

Results from this study and data developed during the June 1 and June 12 investigations (discussed in Section I) were used to develop a general profile of volatile organic contamination at the Minerva site. The distribution of volatile organics in soils and sediment was also compared with the distribution of residual PCBs documented in the June 20, 1983 report. The relationship between volatile organics in soils and sediments at the site and the incidence of these compounds in groundwater samples was evaluated as well. The distribution of volatile organics in groundwater was then correlated with groundwater characteristics delineated as part of an ongoing groundwater

FIGURE 3
LOCATIONS OF CORE SAMPLES COLLECTED FROM
THE WAX DITCH AT THE TRW MINERVA SITE
JUNE 1984

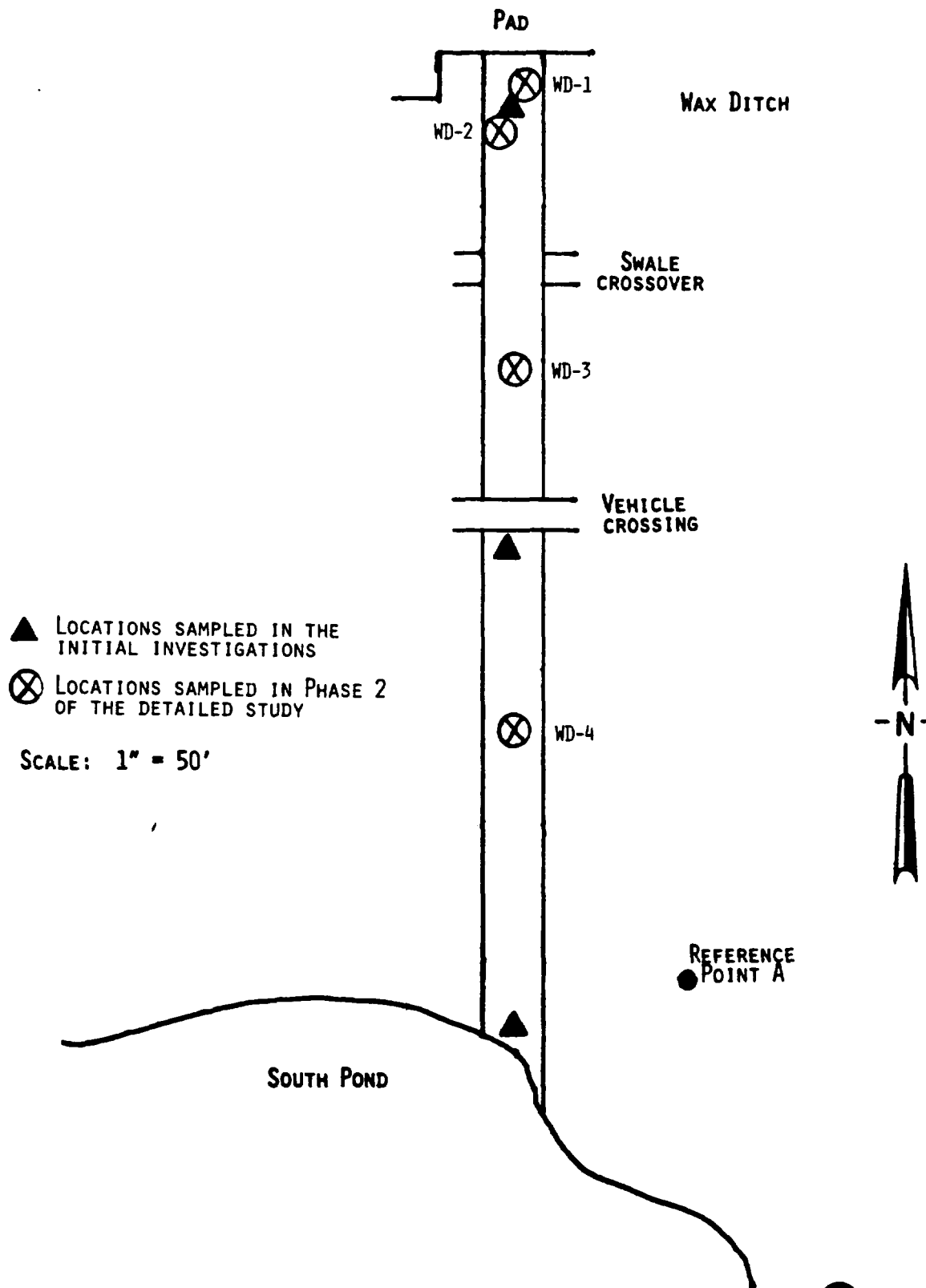


TABLE 3
RESULTS OF VOLATILE ORGANIC ANALYSES OF WAX DITCH CORE
SAMPLES FROM THE TRW MINERVA SITE
(July 1984)

Sample Location	Depth ^a	Compounds Detected ^b	Concentration (ppm)
Wax Ditch No. 1	Surface	1,1,1-Trichloroethane	440
	1 foot	1,1,1-Trichloroethane	180,000
	2 feet	1,1,1-Trichloroethane	50,000
	Clay	1,1,1-Trichloroethane	3,700
Wax Ditch No. 2	Surface	1,1,1-Trichloroethane	60
	1 foot	1,1,1-Trichloroethane	18,000
	2 feet	1,1,1-Trichloroethane	9,400
	Clay	1,1,1-Trichloroethane Trichloroethene	50 22
Wax Ditch No. 3	Surface	1,1,1-Trichloroethane	750
	1 foot	1,1,1-Trichloroethane	9
	2 feet	No Positive Results ^c	
	Clay	1,1,1-Trichloroethane Trans-1,2-dichloroethene	Trace ^d 13
Wax Ditch No. 4	Surface	1,1,1-Trichloroethane	5
		1,1-Dichloroethane	2
	1 foot	1,1,1-Trichloroethane	290
	2 feet	1,1,1-Trichloroethane	120
		Tetrachloroethene	4
	Clay	1,1,1-Trichloroethane Tetrachloroethene	58 18

^a"Clay" represents the clay material underlying the waxy residues in the ditch.

^bOnly positive results are presented. The detection limit is 1 ppm unless otherwise stated.

^cThe detection limit was 5 ppm.

^d"Trace" means detected at less than "the detection limit" of 1 ppm.

FIGURE 4
LOCATIONS OF CORE SAMPLES COLLECTED FROM SOUTH POND
AT THE TRW MINERVA SITE, JUNE, 1984

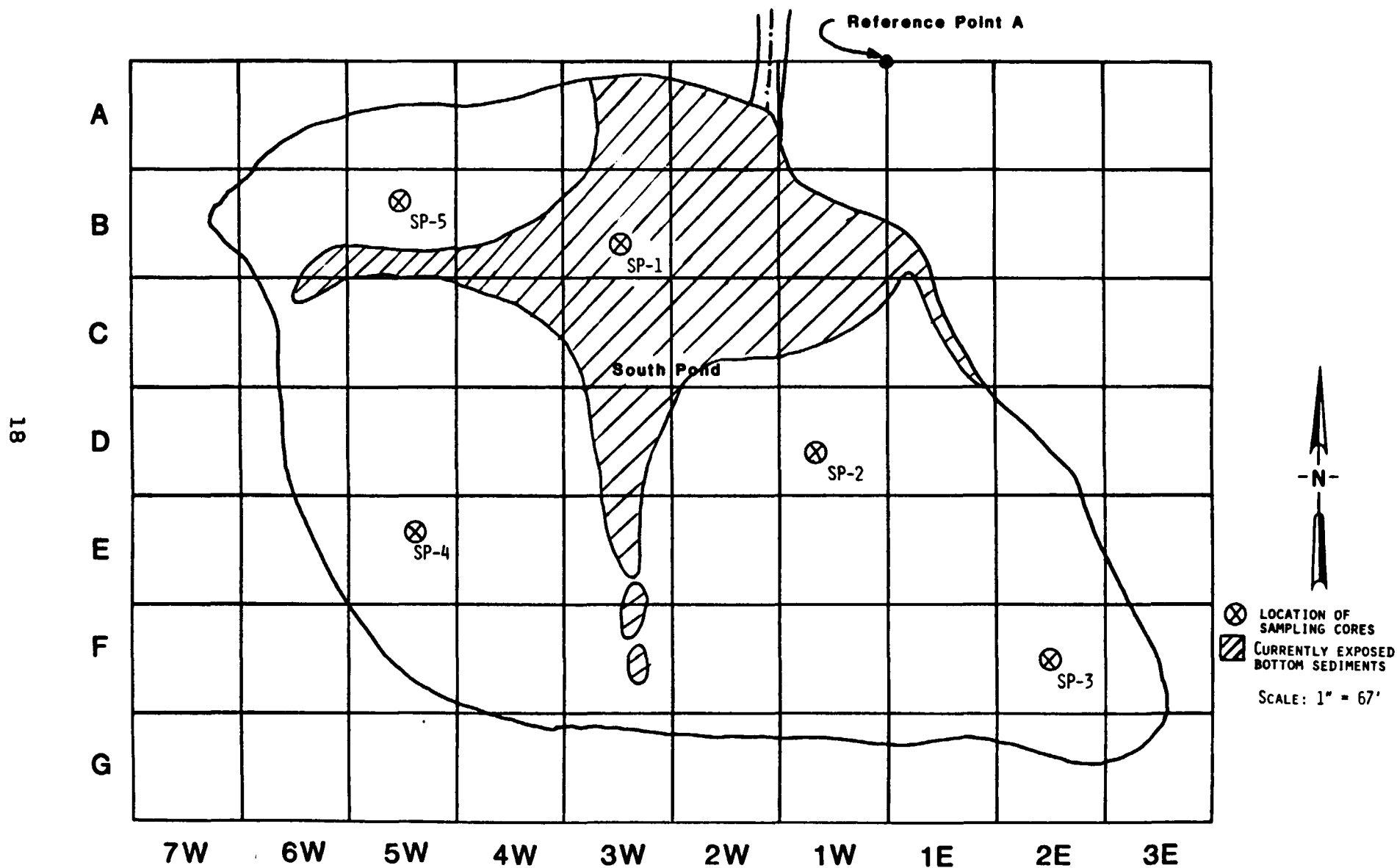


TABLE 4

RESULTS OF VOLATILE ORGANIC ANALYSES OF SOUTH POND CORE
 SAMPLES FROM THE TRW MINERVA SITE
 (July 1984)

Sample Location	Depth ^a	Compounds Detected ^b	Concentration (ppm)
South Pond No. 1	Surface	1,1,1-Trichloroethane	89
		Tetrachloroethene	3
	1 foot	1,1,1-Trichloroethane	90
		Trichloroethene	Trace ^c
	Clay	No positive results	
South Pond No. 2	Surface	No positive results	
	1 foot	Tetrachloroethene	20
	Clay	No positive results	
South Pond No. 3	Surface	1,1,1-Trichloroethane	16
	1 foot	No positive results	
	Clay	No positive results	
South Pond No. 4	Surface	1,1,1-Trichloroethane	4
	1 foot	No positive results	
	Clay	Tetrachloroethene	12
South Pond No. 5	Surface	Tetrachloroethene	5
	1 foot	No positive results	
	Clay	1,1,1-Trichloroethane	3

^a"Clay" represents the clay layer underlying the sediments in South Pond.

^bOnly positive results are presented. The detection limit is 1 ppm unless otherwise stated.

^c"Trace" means detected at less than the 1 ppm "limit of detection."

FIGURE 5
LOCATIONS OF CORE SAMPLES COLLECTED FROM THE
RUBBLE PILE AT THE TRW MINERVA SITE, JUNE 1984

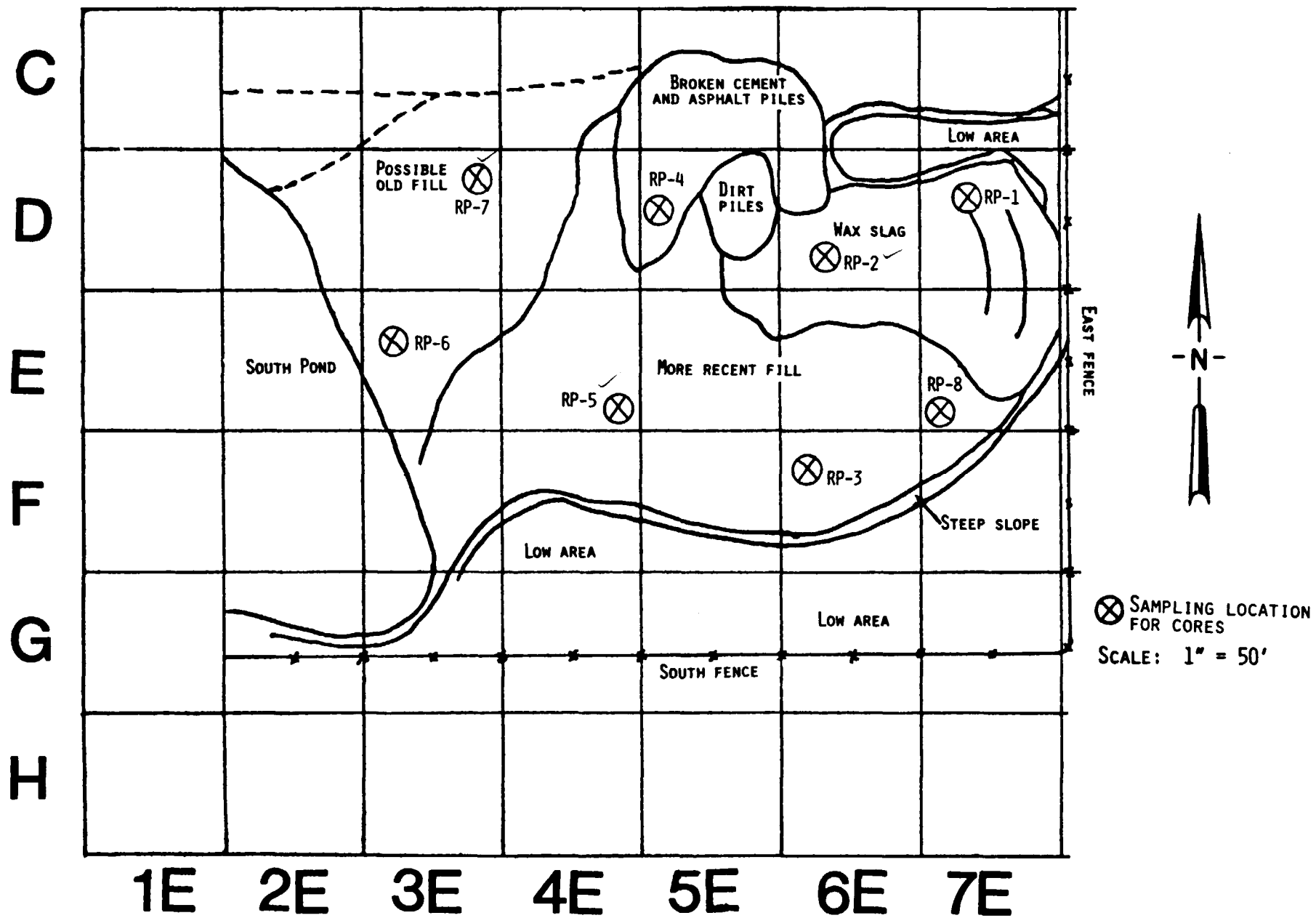


TABLE 5
RESULTS OF VOLATILE ORGANIC ANALYSES OF RUBBLE PILE
CORE SAMPLES FROM THE TRW MINERVA SITE

(July 1984)

Sample Location	Depth	Compounds Detected ^a	Concentration (ppm)
Rubble Pile No. 1	1 foot	No positive results	
	2 feet	No positive results	
	5 feet	No positive results	
Rubble Pile No. 2	1 foot	1,1,1-Trichloroethane	2
	2 feet	1,1,1-Trichloroethane	12
		1,1-Dichloroethane	Trace ^b
		Trichloroethene	Trace ^b
		trans-1,2-Dichloroethene	5
		Tetrachloroethene	Trace ^b
	5 feet	1,1,1-Trichloroethane	7
		1,1-Dichloroethane	7
		Trichloroethene	5
		1,1-Dichloroethene	6
		trans-1,2-Dichloroethene	9
		Tetrachloroethene	5
Rubble Pile No. 3	1 foot	1,1,1-Trichloroethane	12
	2 feet	1,1,1-Trichloroethane	24
	5 feet	Sample not collected ^c	
Rubble Pile No. 4	1 foot	No positive results	
	2 feet	No positive results	
	5 feet	No positive results	
Rubble Pile No. 5	1 foot	1,1,1-Trichloroethane	60
		Trichloroethene	10
	2 feet	1,1,1-Trichloroethane	900
		Trichloroethene	91
	5 feet	1,1,1-Trichloroethane	20,000 ^d
Rubble Pile No. 6	1 foot	Not yet analyzed	
	2 feet	1,1,1-Trichloroethane	2
	5 feet	No positive results	

TABLE 5 (continued)

Sample Location	Depth	Compounds Detected ^a	Concentration (ppm)
Rubble Pile No. 7	1 foot	1,1,1-Trichloroethane	7
		Trichloroethene	2
		trans-1,2-Dichloroethene	2
	2 feet	1,1,1-Trichloroethane	3
		Trichloroethene	3
		trans-1,2-Dichloroethene	3
	5 feet	Not yet analyzed	
Rubble Pile No. 8	1 foot	Not yet analyzed	
	2 feet	1,1,1-Trichloroethane	5
	5 feet	1,1,1-Trichloroethane	3

^aOnly positive results are presented. Limit of detection is 1 ppm unless otherwise stated.

^bTrace means detected at less than the 1-ppm limit of detection.

^cThis sample could not be collected because a concrete block prevented advancement of the sampling device.

^dBecause of the concentration of 1,1,1-trichloroethane detected, the limit of detection for the remainder of this sample was 50 ppm.

monitoring program associated with the original PCB study at the site.

A. Volatile Organics in Soils and Sediments

Results of soil and sediment analyses generally support the hypothesis that the wax ditch, South Pond and rubble pile represent important potential sources of volatile organics at the Minerva site. However, because the concentrations of volatile organics in South Pond sediments and the rubble pile are generally low, the relative potential of these areas to act as future sources is less certain. Volatile organic contamination in all three areas consists predominantly of TCA with traces of five other compounds--1,1-dichloroethane, 1,1-dichloroethene, trans-1,2-dichloroethene, tetrachloroethene, and TCE.

As indicated in Table 3, the concentration of TCA is high in the residues in the wax ditch. One sample contains 18% TCA and the average concentration in the waxy residue is 1.7%. Concentrations of TCA decrease with depth but are present even in the strata underlying the residue. Concentrations also decrease southward along the trench, which may indicate losses are occurring with time since the waxes in the southern end of the ditch are older than waxes in the northern end closer to the plant. Though four other compounds (TCE, trans-1,2-dichloroethene, 1,1-dichloroethane, and tetrachloroethene) have also been detected in wax ditch material, their concentrations are insignificant compared to TCA. The highest concentration of any of the trace compounds was 22 ppm of TCE and the combined

average concentration is less than 10 ppm. The incidence of these compounds is also limited; except for TCA, no other compound was detected in more than 2 of 16 samples.

Volatile organics detected in South Pond include TCA, TCE, and tetrachloroethene (Table 4). As in the wax ditch, TCA predominates. However, concentrations of all compounds detected in pond sediments (including TCA) are relatively low. The highest concentration detected was 90 ppm TCA and the average TCA concentration is less than 20 ppm.

With the exception of the set of samples collected from a single core, concentrations of volatile organics in the rubble pile are low (Table 5). Concentrations average less than 4 ppm for all of the six compounds present (TCA, TCE, tetrachloroethene, 1,1-dichloroethane, 1,1-dichloroethene, and trans-1,2-dichloroethene). The three samples collected from a single core, however, exhibit TCA concentrations up to 20,000 ppm and TCE concentrations up to 91 ppm. In this core sample, the concentrations also appear to be increasing with depth. This "hot spot" in the rubble pile is located approximately 80 feet east of South Pond in an area containing more recent fill and discarded materials.

Several trends are revealed by a comparison of the distribution of volatile organics presented above, and the distribution of PCBs presented in the June 20, 1983 report. It must be emphasized, however, that similarities between these two distributions are coincidental because the use and handling (and, therefore,

the method of introduction) of PCBs and volatile organics at the site were unrelated. Though both PCBs and volatile organics (principally TCA) are found in the wax ditch, South Pond and the rubble pile, only PCBs are found in the swale. This difference is likely due to the fact that PCBs were stored out on the back pad of the plant while spent solvents apparently were not. The back pad drains to the swale. Second, concentrations of PCBs and TCA are both high in the wax ditch though the concentration of TCA decreases southward along the ditch (away from the plant) and the concentration of PCBs increases. This is explained by the fact that older waxy residues lie further south along the ditch and PCB use at the site ceased in 1975 while TCA use began in 1972 and continues through the present.

Concentrations of TCA are higher than PCBs in the wax ditch but lower in the South Pond and the rubble pile. Since TCA was introduced more recently to the ditch, a smaller percentage may have traversed the ditch and settled in pond sediments. Concentrations of TCA in the rubble pile are likely lower than PCBs for several reasons. First, much of the waxy residue in the rubble pile may have been placed before the introduction of TCA to the site began in 1972. Second, TCA contamination does not appear to be present in areas at the site other than the wax ditch and South Pond so that debris placed in the rubble pile from other areas at the site would not likely contribute TCA to the rubble pile. Finally, as described later, TCA and

other volatile organics are relatively mobile and may be depleted in some areas of the site.

B. Volatile Organics in Groundwater

Results of volatile organic analyses of groundwater samples were presented in Table 1. Nine volatile organic compounds have been consistently detected in groundwater monitoring wells at the TRW Minerva site. The most prevalent of these (TCE, trans-1,2-dichloroethene, and 1,1-dichloroethane) have been detected at concentrations exceeding 1 ppm and exhibit a similar pattern of occurrence. The remaining six compounds, chloroethane, chloroethene, 1,2-dichloroethane, 1,1-dichloroethene, TCA, and 2-propanone have been detected at lower concentrations and do not exhibit a consistent pattern of occurrence. Chloroethane has been consistently detected in wells 13 and 18 and reached a concentration of 270 ppb in well 18. The remaining five compounds have been detected consistently in only one or two wells each and concentrations have not exceeded 50 ppb.

Though volatile organic analyses have only been performed over the last several months, almost two years of groundwater data have been collected as part of the ongoing monitoring program established as part of the investigation of PCBs at the site. Groundwater levels, presented in Table 6, and PCB concentrations, presented in Table 7, have been monitored monthly in selected wells since they were installed in 1982. Groundwater contours developed from the data in Table 6 indicate that groundwater flow is generally toward the south. Although the actual

levels may vary seasonally by several feet (as indicated in Table 6), groundwater gradients in the area are not severely affected by seasonal variations so that groundwater flow patterns do not vary significantly throughout the year. This is illustrated by comparing the low-flow (fall) contours presented in Figure 6 with the high-flow (spring) contours presented in Figure 7.

Typical concentrations of TCE exhibited in groundwater at the Minerva site are depicted in Figure 8. Based on a comparison of this pattern with the output of a computer flow model (documented in the June 20, 1983 report) it appears that potential TCE sources at the site (specifically, the wax ditch, South Pond and the rubble pile) may be contributing volatile organics to groundwater. Concentrations in wells 10, 11 and 19 suggest that a small, localized portion of either the wax ditch or South Pond may be contributing limited quantities of volatile organics. Compounds from this source are proceeding slowly downgradient and are detected first in well 10 and then, in greater concentrations, in well 19. The lack of detection in well 18 and the limited detection in well 11 indicate that the apparent plume is quite narrow.

The average distribution of PCBs detected in groundwater at the TRW site is depicted in Figure 9. Interestingly, a comparison of Figures 8 and 9 indicate that, except for well 13, PCBs appear in the same wells as TCE. Although the relative

TABLE 6

GROUNDWATER ELEVATION IN WELLS AT THE TRW SITE
MINERVA, OHIO

Ground Elevation (feet)	Sampling Dates									
	Well	04/81	08/10/82	10/08/82	10/28/82	11/15/82	11/23/82	12/14/82	01/04/83	02/18/83
1066.4	1	1062.2	1059.0	1058.4	1058.3	1058.6	1058.7	1058.6	1059.8	1060.2
1065.8	2	1062.1	1058.8	1058.2	1058.1	1058.4	1058.8	1058.4	1059.6	1059.8
1065.0	3	1061.9	1059.0	1058.5	1058.3	1058.6	1058.8	1058.6	1059.7	1059.8
1065.0	4	1062.1	1059.9	1059.3	1059.1	1059.7	1060.0	1059.7	1060.4	1060.7
1087.0	5	1060.6	1057.8	1057.3	1057.2	1057.3	1057.5	1057.4	1058.8	1059.0
1076.0	6	1053.4	1057.6	1057.1	1056.9	1057.1	1057.4	1057.2	1058.5	1058.3
1076.0	7	---	1057.6	1057.1	1056.9	1057.2	1057.4	1057.2	1058.4	1058.6
1069.5	8	1059.7	1057.5	1057.2	1057.0	1057.2	1057.5	1057.2	1058.3	1058.4
1060.0	9	1058.9	1056.9	1056.6	1056.4	1056.6	1056.9	1056.5	1057.5	1057.4
1060.0	10	1059.0	1056.2	1055.9	1055.9	1055.9	1056.2	1056.3	1056.9	1057.0
1060.0	11	1057.9	1056.3	1056.0	1058.9	1056.0	1056.3	1056.3	1057.0	1057.1
1060.0	12	1057.8	1056.3	1055.9	1055.9	1056.1	1056.3	1056.3	1057.1	1057.2
1061.8	13	1059.1	1056.7	1056.3	1056.2	1056.4	1056.6	1056.4	1057.4	1057.6
1062.3	13a	1061.1	1056.9	1056.6	1056.6	1056.8	1056.8	1056.8	1057.9	1058.2
1066.2	14	1059.3	1057.2	1056.8	1056.7	1056.9	1057.1	1056.9	1058.0	1058.1
1068.5	15	---	1058.3	1057.8	1057.8	1057.9	1058.1	1058.0	1059.2	1059.5
1068.5	16	---	1058.3	1057.9	1057.7	1057.9	1058.1	1058.0	1059.2	1059.3
1068.8	17	---	1058.6	1058.1	1058.0	1058.2	1058.4	1058.2	1059.4	1059.6
1059.8	18	---	---	---	---	---	1056.2	1056.2	1056.9	1057.1
1058.4	19	---	---	---	---	---	1055.9	1055.8	1056.5	1056.8
1059.5	20	---	---	---	---	---	1055.8	1055.8	1056.5	1056.7
1059.5	21	---	---	---	---	---	1056.2	1056.3	1057.0	1057.1
1062.9	Pond	---	1063.7	---	---	---	---	---	1063.7	---

^aWater elevations reported in feet above mean seal level (msl)

TABLE 6 (continued)

Ground Elevation (feet)	Sampling Dates										
	3/30/83	4/27/83	5/22/83	6/28/83	7/28/83	9/8/83	10/11/83	10/31/83	1/17/84	2/24/84	3/16/84
1066.4	1061.7	1062.3	1062.3	1060.1	1059.5	1058.6	1058.5	1058.7	1060.0	1060.9	1062.9
1065.8	1060.7	1061.5	1061.3	1059.8	1059.8	1058.3	1058.4	1058.5	1059.1	1060.1	1062.4
1065.0	1060.5	1061.3	1061.0	1059.8	1059.4	1058.5	1058.5	1058.7	1059.6	1060.1	1060.4
1065.0	1061.2	1061.7	1061.6	1060.4	1060.1	1059.1	1059.2	1059.4	1060.1	1060.1	1061.4
1087.0	1060.2	1061.7	1061.4	1059.1	1058.4	1057.6	1057.4	1057.6	1057.8	1059.4	1059.7
1076.0	1958.6	1060.3	1060.0	1058.7	1058.0	1056.2	1057.2	1057.6	1057.8	1059.0	1059.2
1076.0	1059.6	1060.4	1060.4	1058.6	1057.8	1057.2	1057.2	1057.4	1057.2	1059.0	1059.2
1069.5	1059.1	1059.5	1059.5	1058.4	1058.0	1057.3	1057.2	1057.3	1057.5	1058.6	1059.2
1060.0	1058.2	1058.5	1058.4	1057.6	1057.2	1056.7	1056.6	1056.0	1057.4	1058.0	1059.1
1060.0	1057.7	1058.3	1058.0	1057.0	1056.5	1056.0	1055.9	1056.0	1056.8	1057.3	1058.2
1060.0	1057.9	1058.5	1058.2	1057.1	1056.6	1056.1	1056.0	1056.1	1057.0	1057.4	1058.2
1060.0	1058.2	1058.6	1058.3	1057.2	1056.7	1056.1	1056.1	1056.3	1057.0	1057.5	1058.3
1061.8	1058.4	1059.0	1059.1	1057.6	1057.1	1056.5	1056.1	1056.5	1057.4	1058.0	1059.0
1062.3	1058.9	1059.5	1059.4	1058.0	1057.5	1056.9	1056.8	1057.0	1057.9	1058.5	1059.9
1066.2	1058.9	1059.6	1059.4	1058.2	1057.6	1057.0	1056.9	1057.1	1058.0	1058.4	1059.1
1068.5	1060.1	1060.9	1060.6	1059.4	1058.9	1058.0	1058.0	1058.1	1059.3	1059.6	1060.0
1068.5	1060.0	1061.0	1060.7	1059.5	1058.8	1058.1	1058.0	1058.1	1059.0	1059.7	1059.9
1068.8	1060.4	1061.2	1060.0	1060.0	1059.1	1058.3	1058.3	1058.5	1058.9	1059.7	1060.3
1059.8	1057.8	1058.2	1058.1	1057.1	1056.6	1056.0	1056.0	1058.1	1056.9	1057.3	1058.2
1058.4	1057.3	1057.9	1057.6	1056.6	1056.1	1055.7	1055.6	1055.2	1056.5	1056.9	1058.0
1059.5	1057.4	1057.9	1057.7	1056.6	1056.2	1055.6	1055.6	1055.7	1056.4	1056.9	1057.8
1059.5	1057.9	1058.4	1058.2	1057.1	1056.6	1056.0	1056.0	1056.1	1056.4	1057.5	1058.4
1062.9	1063.40					1062.9	1062.2	1062.1	--	1063.5	--

TABLE 6 (continued)

Ground Elevation (feet)	Sampling Dates		
	Well	5/24/84	6/28/84
1066.4	1	1063.3	1060.1
1065.8	2	1062.1	1060.0
1065.0	3	1061.1	1060.0
1065.0	4	1061.8	1060.5
1087.0	5	1061.0	1059.1
1076.0	6	1060.1	1058.7
1076.0	7	1060.1	1058.8
1069.5	8	1059.7	1058.4
1060.0	9	1058.8	1057.7
1060.0	10	1058.7	1057.0
1060.0	11	1058.4	1057.1
1060.0	12	1059.1	1057.2
1061.8	13	1059.2	1057.7
1062.3	13a	1059.3	1058.1
1066.2	14	1059.5	1058.3
1068.5	15	1060.5	1059.4
1068.5	16	1060.7	1059.4
1068.8	17	1061.9	1059.8
1059.8	18	1058.4	1057.1
1058.4	19	1058.0	1056.6
1059.5	20	1057.9	1056.6
1059.5	21	1058.5	1057.1
1062.9	Pond	---	1063.7

^aWater elevations reported in feet .

TABLE 7

PCB CONCENTRATIONS (ppt) IN WELL WATER SAMPLES FROM THE TRW SITE
IN MINERVA, OHIO

Well	Sampling Dates									
	Initial 8/11/82	8/11/82 ^a	9/1-9/3/82	10/8/82	10/28/82	11/14/82	11/23/82	12/14/82	1/4/83	2/18/83
1	<20	<20	<20	<20		<20	<20	60 ^a	<20 ^a	<20 ^a
2	<20	<20	<20							
3	22	28	<20							
4	<20	<20	78		100	35				
5	<20	<20	<20							
6	<20	<20	<20							
7	<20	<20	<20							
8	26	<20	25							
9	<20	<20	<20	<20	100	55	<20	40 ^a	<20 ^a	<20 ^a
10	364	462	1,020	770	560	240	360	390, 760 ^a	370, ^a 150 ^b	340 ^a 340 ^{a, c}
11	<20	<20	65	40	120	60	55	50 ^a	<20 ^a	<20 ^a
12	72	105	165	180	180	155	25	80 ^a	80 ^a	50 ^a
13	97	<20	<20	30	140	<20	<20 ^a	<20 ^a	<20 ^a	<20 ^a
13a	<20	<20	<20				<20			
14	95	25	<20							
15	<20		<20							
16	414	76	<20	<20						
17	<20	23	<20							
18							<20, <20 ^a	<20 ^a	<20 ^a	30 ^a
19							60, 50 ^a	40 ^a	<20 ^a	45 ^a
<20							30, <20 ^a	<20 ^a	<20 ^a	<20 ^a
21							25, <20 ^a	<20 ^a	<20 ^a	
Pond									4500	7400 ^e

^aAfter evacuation^bAfter filtering^cDuplicate^dAfter extended settling^eAverage of four samples from different locations

TABLE 7 (continued)

Well	Sampling Dates								
	3/30/83	4/27/83	5/22/83	6/28/83	7/28/83	9/8/83	10/11/83	10/31/83	1/17/84 ^a
1	<20 ^a	<20 ^a	<20	<20	<20	<20	<20	<20	<20
2			22	28	<20				
3			<20	<20	78		100	35	
4			<20	<20	<20				
5			<20	<20	<20				
6			<20	<20	<20				
7			26	<20	25				
8			610, 450 ^b	580, 230 ^b	400, 510 ^b	560 ^b	870		
9	180 ^{a, d}	340 ^a	410 ^a , 320 ^{a, b}	<20	<20	140	<20	<20	
10	20 ^a	<20 ^a	88	43	36	100	82	<20	50
11									
12									
13									
13a									
14									
15									
16	30 ^a	70 ^a	260	200	160	160	130	20	120
17	<20 ^a	<20 ^a	<20	<20	<20	<20	<20	<20	23
18									
19									
<20									
21									
Pond									

^aAfter evacuation^bAfter filtering^cDuplicate^dAfter extended settling^eAverage of four samples from different locations

TABLE 7 (continued)

Well	Sampling Dates			
	2/24/84 ^a	3/16/84 ^a	5/24/84	6/28/84
1	<20	<20	<20	<20
2				
3				
4				
5				
6				
7				
8				
9				
10	230	110	100	430
11	<20	<20	20	50
12	30	80	50	<20
13				
13a				
14				
15				
16				
17				
18	40	40	40	70
19	<20	<20	<20	<20
<20				
21				
Pond				

^aAfter evacuation^bAfter filtering^cDuplicate^dAfter extended settling^eAverage of four samples from different locations

FIGURE 6
TYPICAL GROUNDWATER CONTOURS FOR FALL (LOW-FLOW)
CONDITIONS AT THE TRW MINERVA SITE

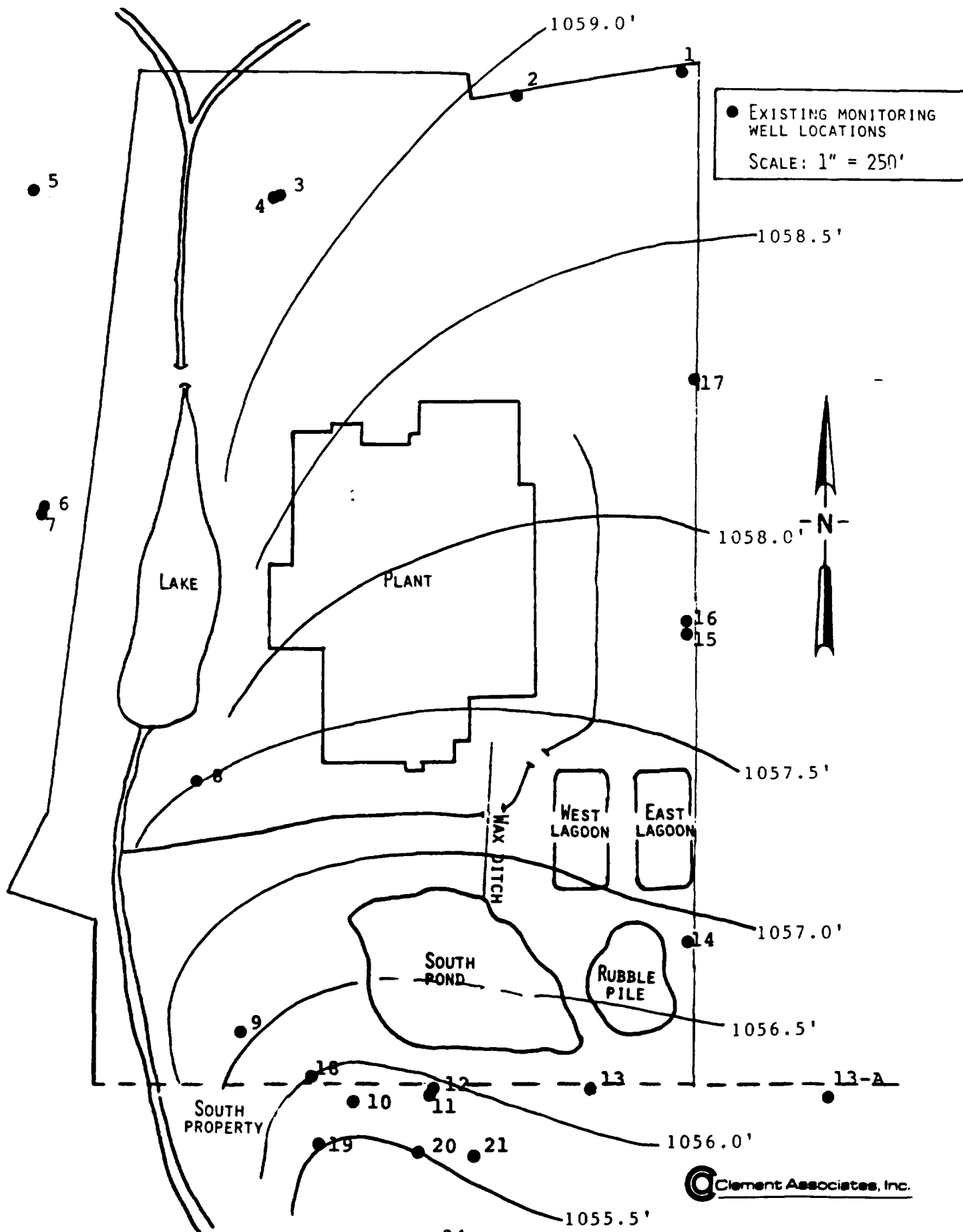


FIGURE 7

TYPICAL GROUNDWATER CONTOURS FOR SPRING (HIGH-FLOW) CONDITIONS AT THE TRW MINERVA SITE

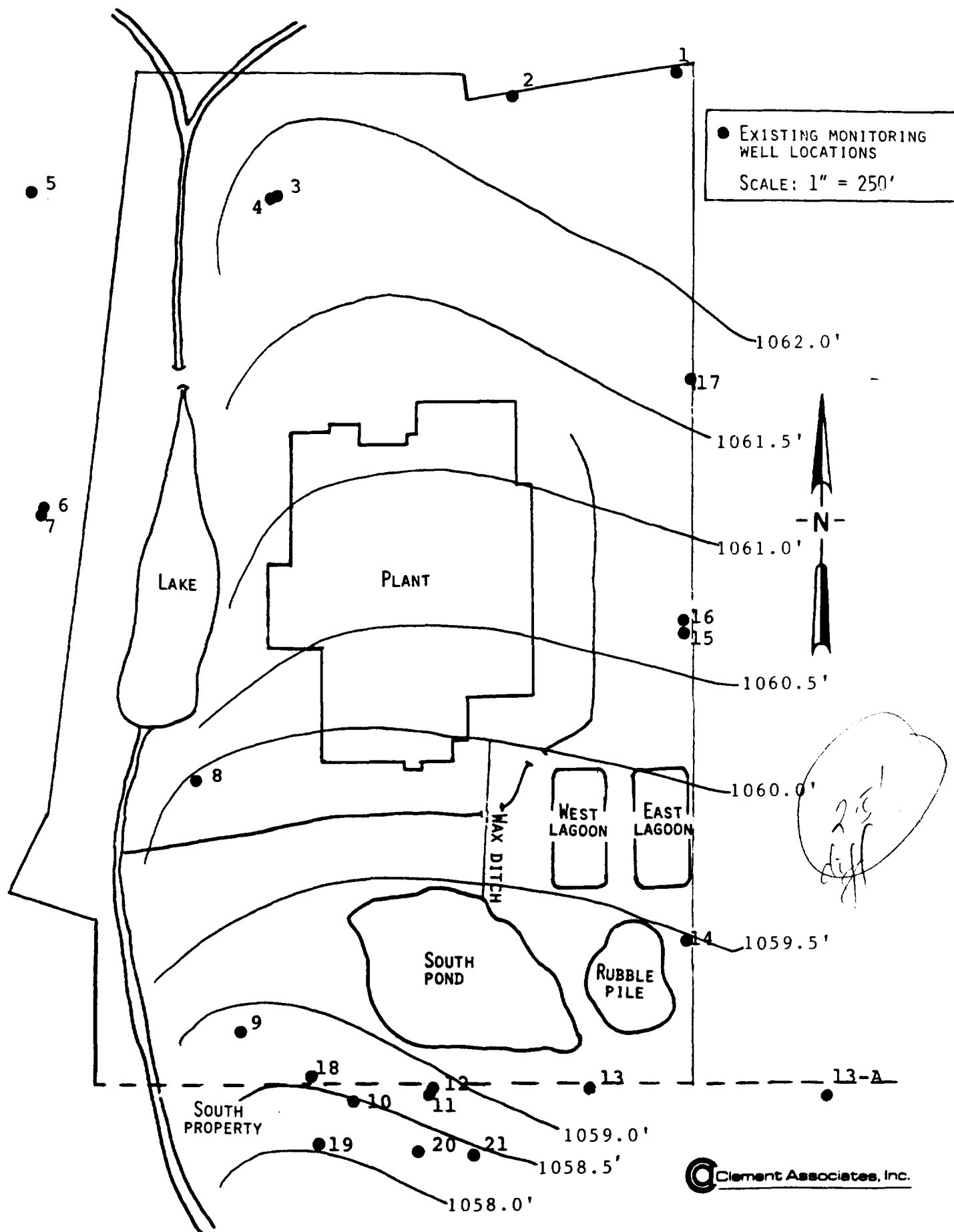
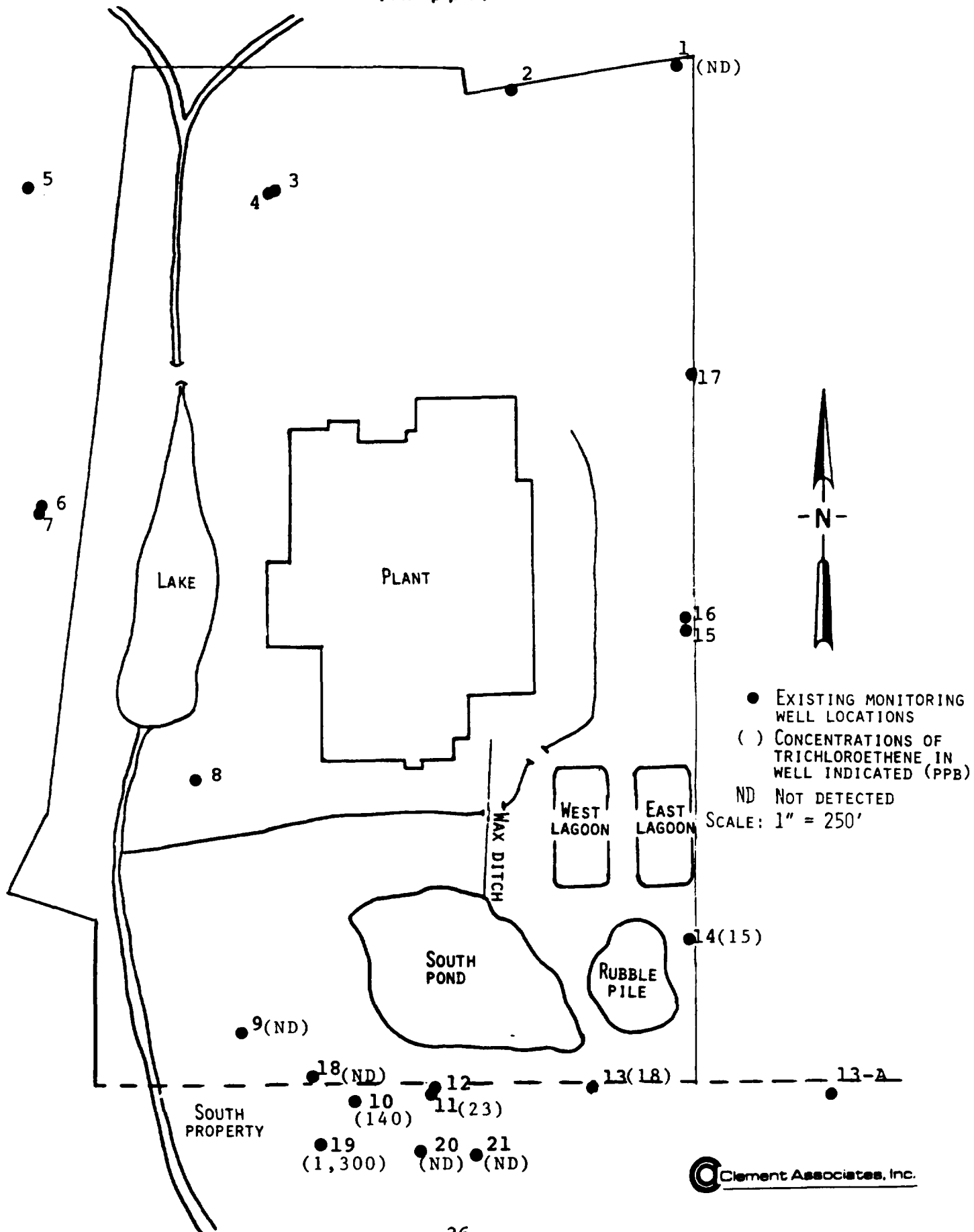


FIGURE 8
CONCENTRATIONS OF TRICHLOROETHENE
IN GROUNDWATER AT THE TRW MINERVA SITE
(in ppb)



concentrations of these compounds differ by three orders of magnitude,¹ it is likely that TCE and PCBs are originating from the same small source in the wax ditch or the South Pond. The appearance of TCE in well 13 potentially indicates another active source on the TRW property in the region of the rubble pile.

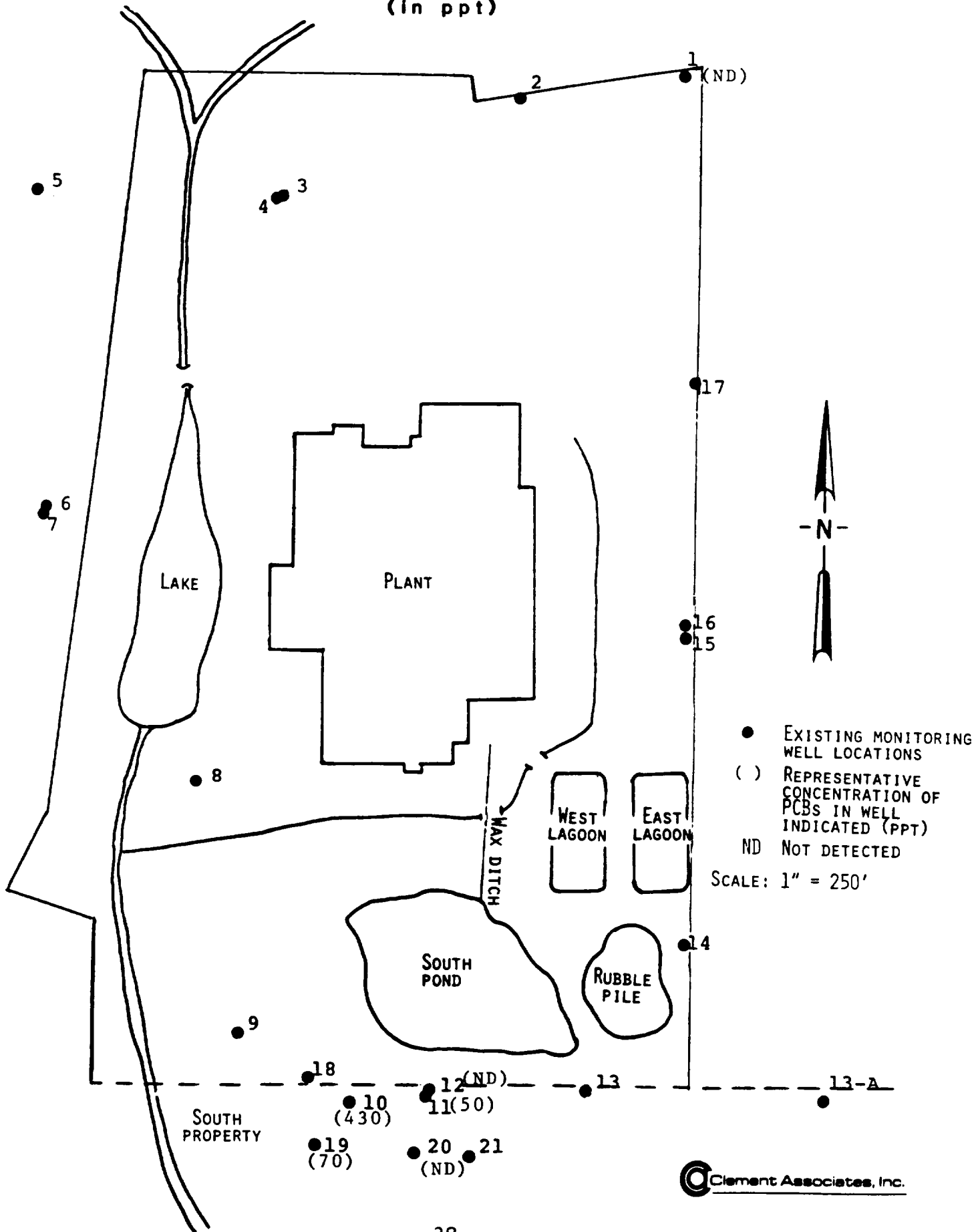
One difference in the distributions depicted in Figures 8 and 9 is that TCE concentrations increase with distance down-gradient while PCB concentrations decrease, suggesting that the front of the PCB plume is being detected but that the front and in fact, the peak, of the TCE plume has passed. This is explained by the fact that TCE is more mobile in the environment than PCBs. A discussion of the properties and relative mobilities of volatile organics and PCBs is presented in Section III of this report.

The distribution of trans-1,2-dichloroethene and 1,1-dichloroethane presented in Figures 10 and 11, respectively, parallel that of TCE. These compounds, like TCE, are considerably more mobile than PCBs in the environment.

Since December 1983, additional water quality parameters (pH, specific conductance, and total organic halogen-TOX) have also been monitored monthly at the TRW site. Results of these analyses are presented in Table 8. Several of these parameters

¹ PCB concentrations in groundwater are minimal and results of a risk assessment documented in the June 20, 1983 report indicate that potential risks associated with PCBs detected in groundwater are also minimal.

FIGURE 9
REPRESENTATIVE CONCENTRATIONS OF PCBs
IN GROUNDWATER AT THE TRW MINERVA SITE
(in ppt)



correlate with results of volatile organic analyses. For example, the distribution of values for total organic halogen (TOX) are presented in Figure 12. Comparison of Figures 9, 10, 11 and 12 indicate that TOX correlates reasonably well with the individual and combined concentrations of the predominant volatile organic compounds presented in groundwater at the site.

Interestingly the trace volatile organic chloroethene has been detected in precisely the two wells (Nos. 11 and 19) exhibiting the highest pH. Since it is generally known that alkaline conditions catalyze the dehydrohalogenation of chlorinated ethanes (see for example Morrison and Boyd 1972), it is possible that chloroethene is being formed by dehydrohalogenation of the other chlorinated hydrocarbons present in these wells.

It should be noted that the principal volatile organic compound detected in soils and sediments on the TRW property, TCA, does not correspond to any of the principal components detected in groundwater (TCE, trans-1,2-dichloroethene, and 1,1-dichloroethane). At the same time, the compounds detected in groundwater are present only at very low concentrations in soils and sediments at the TRW site. These observations are understandable in terms of the site history, however, and are considered in greater detail in the following section.

FIGURE 10
CONCENTRATIONS OF TRANS-1,2-DICHLOROETHENE
IN GROUNDWATER AT THE TRW MINERVA SITE
(In ppb)

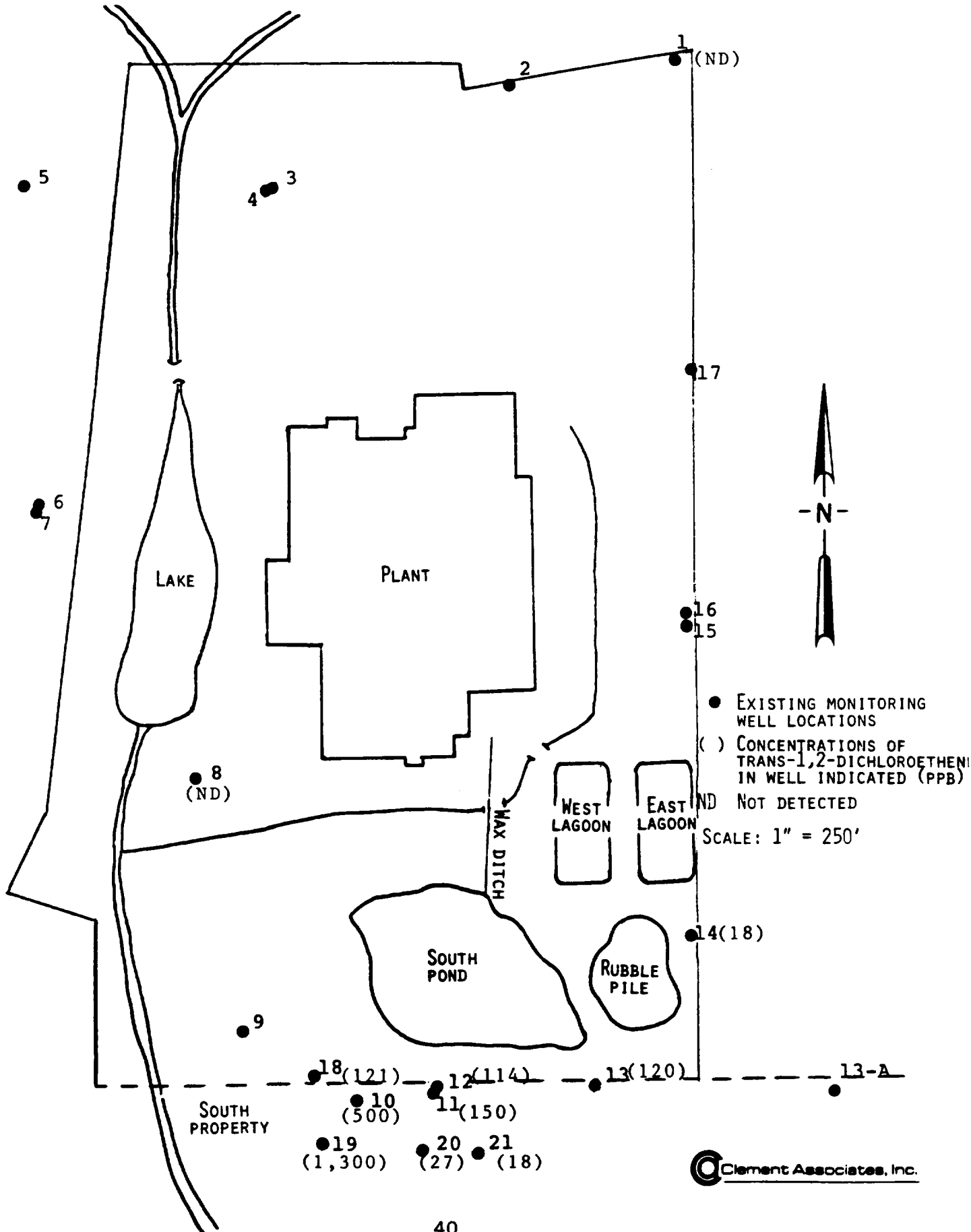


FIGURE 11
CONCENTRATIONS OF 1,1-DICHLOROETHANE
IN GROUNDWATER AT THE TRW MINERVA SITE
(In ppb)

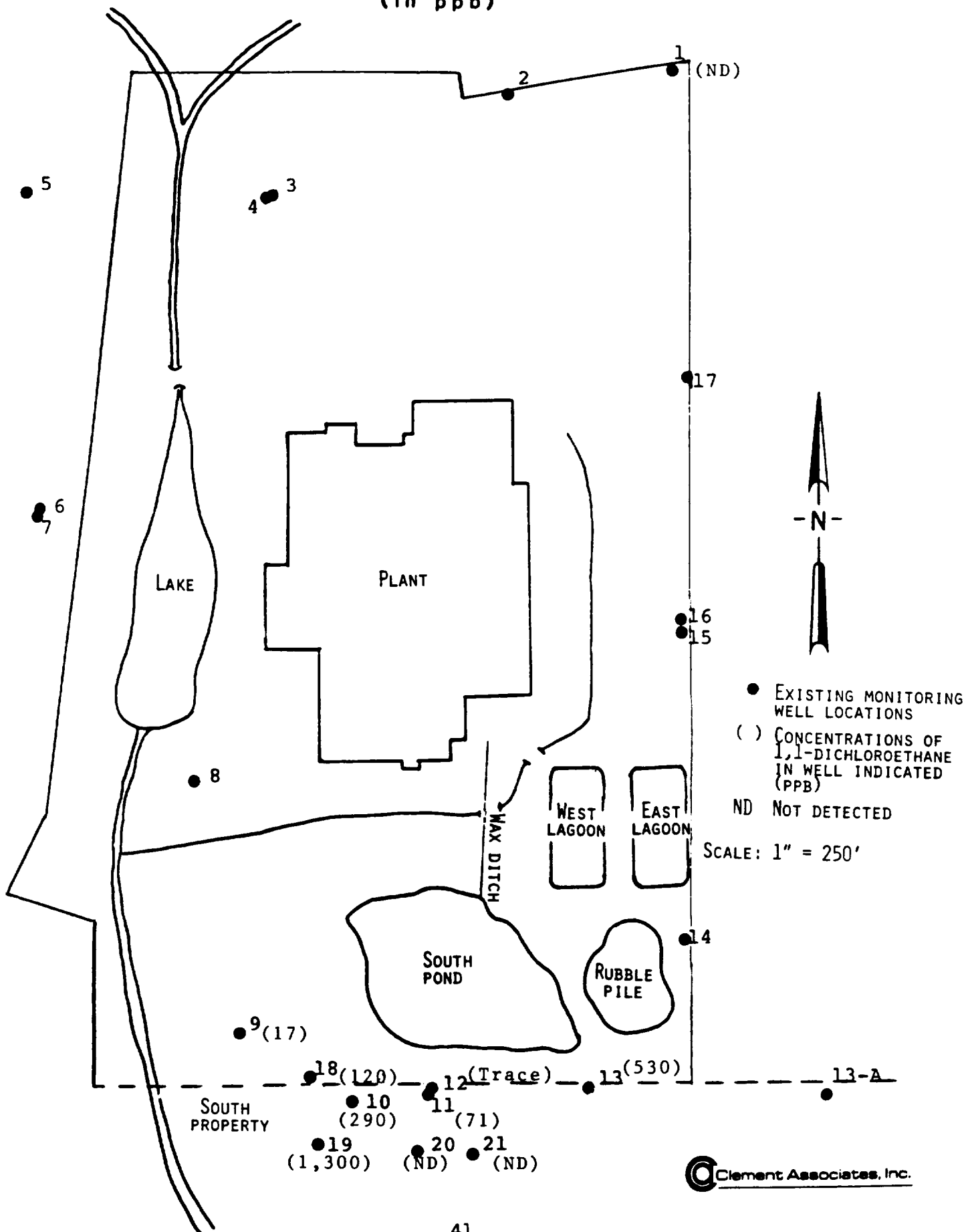
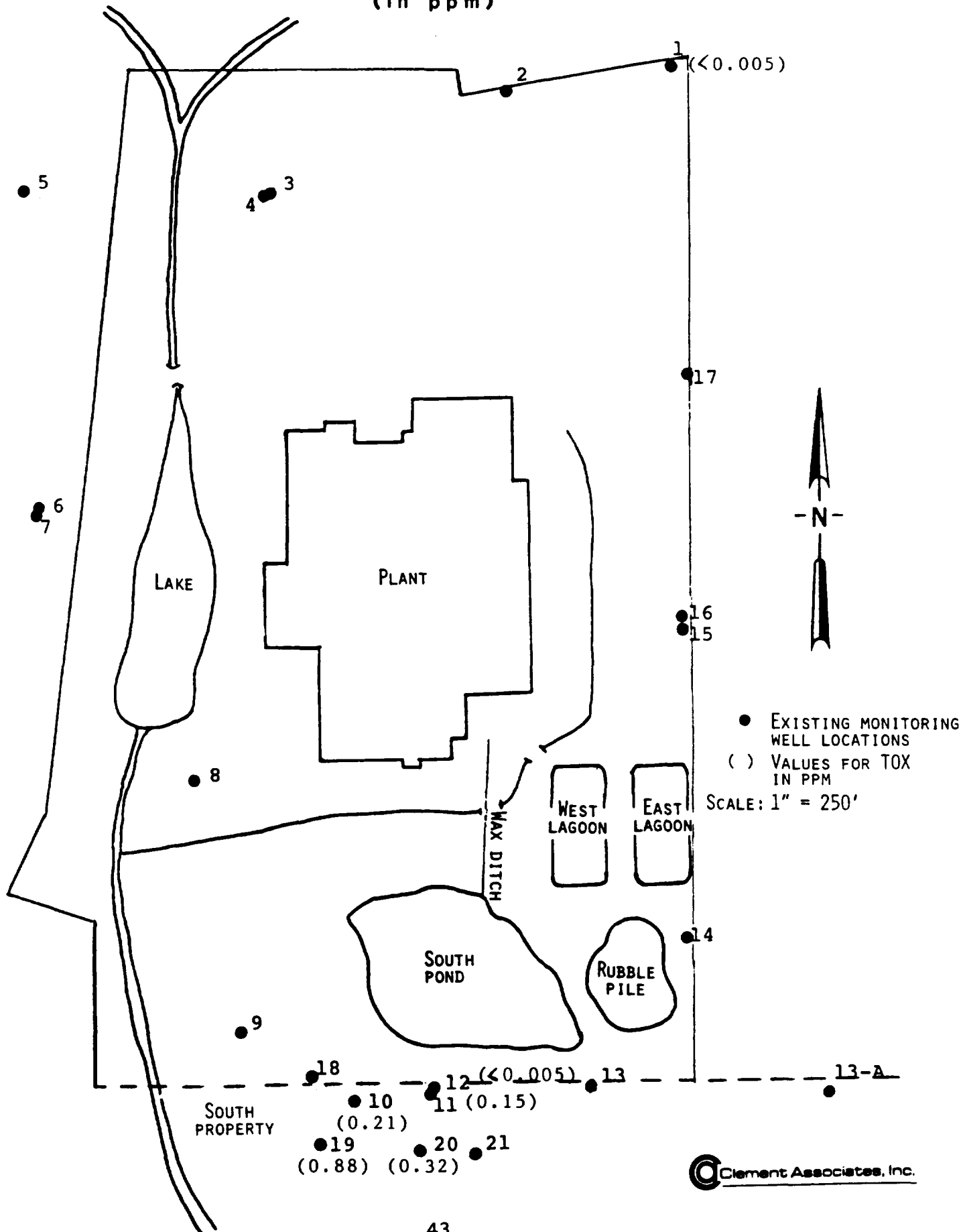


TABLE 8
TSCA WATER QUALITY DATA FOR WELLS AT THE TRW SITE,
MINERVA, OHIO

Well Number	Parameter	Sampling Dates				
		1/17/84	2/24/84	3/16/84	5/24/84	6/28/84
1	PCB Concentration (ppt)	<20	<20	<20	<20	<20
	Specific Conductance (μmhos)	NA	170	130	152	260
	Total Organic Halogen ¹ (mg/liter)	<0.005	0.015	0.016	<0.005	<0.005
	pH	6.5	6.6	6.6	6.4	6.5
10	PCB Concentration	290	230	110	100	430
	Specific Conductance	890	620	470	540	1,400
	Total Organic Halogen	0.16	0.20	0.052	0.061	0.21
	pH	8.0	8.6	8.0	7.5	9.0
11	PCB Concentration	80	<20	<20	20	50
	Specific Conductance	4,300	4,800	1,200	3,900	5,200
	Total Organic Halogen	0.19	0.16	0.052	3.7	0.15
	pH	10.8	11.0	9.3	10.7	11.1
12	PCB Concentration	50	30	80	50	<20
	Specific Conductance	880	1,000	350	700	1,200
	Total Organic Halogen	0.05	0.024	0.024	0.015	<0.005
	pH	6.8	7.8	7.6	6.3	6.8
19	PCB Concentration	120	40	40	40	70
	Specific Conductance	1,480	1,180	400	350	3,500
	Total Organic Halogen	0.69	0.73	0.03	.043	.88
	pH	9.5	9.4	7.8	7.3	10.2
20	PCB Concentration	23	<20	<20	<20	<20
	Specific Conductance	580	475	400	310	600
	Total Organic Halogen	0.02	0.045	0.009	.008	.032
	pH	7.2	8.0	7.9	7.7	7.0

¹TOX

FIGURE 12
TYPICAL VALUES FOR TOTAL ORGANIC HALOGEN (TOX)
IN GROUNDWATER AT THE TRW MINERVA SITE
 (In ppm)



III. RISK ASSESSMENT

Once the distribution of volatile organic compounds in wax ditch residues, South Pond sediments, rubble pile soils and groundwater under the TRW site was characterized, risks associated with the potential migration of volatile organics were evaluated. The individual potential risks posed by the movement of volatile organics alone and the possible effects that the presence of these compounds may have on the transport of PCBs at the site were both considered. Risks first were evaluated assuming that only natural forces would determine the transport of volatile organics at the site subject to conditions of the site that currently exist. However, to evaluate the effectiveness of proposed remedial measures for the site (documented in the December 20, 1983 report) toward minimizing transport of volatile organics, potential risks were also evaluated based on the conditions that will result from the proposed remediation. Since this evaluation showed that the proposed remediation (which was initially designed to address problems associated with PCBs) does not adequately mitigate risks due to volatile organics in groundwater, modifications have been developed that will address outstanding issues. Recommended modifications to the proposed remediation plan are presented in Section IV of this report.

This risk assessment was performed in three steps. First, an exposure assessment was performed in which potential migration

of volatile organics and attendant exposure were evaluated. Then potential health effects associated with the predominant volatile organics detected at the site were evaluated in a toxicology assessment. Finally, risks were evaluated by considering the results of the exposure and toxicology assessments together. Each of these steps is summarized in the following paragraphs.

A. Exposure Assessment

VO discharge to wax ditch (GUES)
12-1980

Since discharging volatile organics into the wax ditch ceased in 1980, potential exposure to volatile organics from the TRW site can occur only through the movement of volatile organic compounds already present in soils, and groundwater at the site. Assuming the situation is not altered intentionally (i.e., by remediation), future migration will occur only by natural dispersion processes which are modeled to estimate potential exposure and attendant risks posed by existing volatile organic contamination. The effectiveness of proposed remedial measures is then judged by modeling natural dispersion under conditions expected to exist as a result of remediation. Possible effects that the presence of volatile organics at the TRW site might have on PCB transport are also examined briefly.

The principal routes of migration considered in this report are volatilization from soils, sediments, and surface water and transport in groundwater.¹ Methods used to model transport

¹A third mechanism, surface runoff, is not considered to be important to the movement of volatile organics at the Minerva site because these materials do not adsorb strongly on soil materials so that transport by this route is considered less important than volatilization or groundwater transport.

and derive exposure estimates for this assessment were detailed in the June 20, 1983 report and are outlined briefly below. It should be noted that in the absence of empirical data, conservative starting assumptions were incorporated into the models so that results of the analysis are likely to be far more severe than actual consequences that might occur at the site. In other words, a "worst-case" evaluation was performed. Since the rate of transport of volatile organics are a function of the properties of these compounds and properties of the matrices through which migration occurs, a discussion of relevant properties is included in this section.

The physicochemical properties of volatile organic compounds detected in soil sediments and groundwater at the Minerva site are presented in Table 9. Properties of Aroclor 1254, the principal PCB mixture present at the site, are also presented for comparison. In contrast to PCBs, the other organics listed in Table 9 are volatile and exhibit substantial vapor pressures at room temperature. All of the compounds listed are also much more soluble in water than PCBs. The logs of the octanol/water partition coefficients for the compounds listed suggest that these compounds, unlike PCBs, will not be readily adsorbed on inorganic soil particles.¹ All of these factors indicate that volatile organics found at the site are more mobile in

¹The relationship between octanol/water partition coefficients and soil adsorption has been investigated in a number of studies. See, for example, McCarty, Reinhard, and Rittman 1981.

TABLE 9

PHYSICAL AND CHEMICAL PROPERTIES OF CHLORINATED ORGANICS FOUND IN GROUNDWATER AT THE TRW MINERVA SITE

Compound	Molecular Weight	Specific Gravity (Water=1)	Melting Point (°C)	Boiling Point (°C)	Vapor Pressure (mmHg at 20-25°C)	Water Solubility (mg/liter at 20-25°C)	Log of the Octanol/Water Partition Coefficient	Henry's Law Constant (atm-m ³ /mole) x 10 ³	References
1,1,1-Trichloroethane	133.4	1.34	-33 to -30.4	74.1	96-100; 123-125	480-1360; 4400	2.17; 2.47	4.9	a,b,c,d,e, f,g,h,i,j, l,m
1,1-Dichloroethane	98.96	1.18	-98; -97.0	57.3	180	5,000; 5,500	1.79	5.48	a,g,i,m
1,2-Dichloroethane	98.96	1.26	-40; -35.4	83.5	60-61	8,000-8,300	1.48	1.1	a,b,e,i,j, l,m
Chloroethane	64.52	0.92	-139; -136	12.3	1,000	5,700-5,740	1.54	—	a,i,k,m
Trichloroethene	131.4	1.46	-87.1 to -84.8; -73	86.7; 87	57.9; 74	1,100	2.29; 2.42	11.7; 12.0	a,b,c,d,e, g,h,i,l,m
1,1-Dichloroethene	96.95	1.21	-122	31.7; 37	591	400; 5,000	1.48	15	a,b,g,i,m
trans-1,2-Dichloroethene	96.94	1.28	-49.4	47.5; 47.7	265	6,300	1.48	5.3	a,c,g,i,m
Chloroethene	62.50	0.91	-160	-14; -13.4	2,660	1.1; 60	0.60	—	a,i,m,n
Aroclor 1254	328.4 (average)	1.5		365-390	7.7x10 ⁻⁵	0.012, 0.024 0.056	6.03	8.34	b,j,m

References:

(a) The Merck Index. 1976. Ninth Edition. Merck and Co., Inc., Rahway, N.J.

(b) U.S. Environmental Protection Agency (USEPA). 1979. Water-Related Environmental Fate of 129 Priority Pollutants. Washington, D.C. December 1979. EPA 440/4-79-029

TABLE 9 (continued)

- (c) Kirk-Othmer. 1979. Chlorocarbons-hydrocarbons. In Encyclopedia of Chemical Technology. John Wiley and Sons, Inc. New York. Volume 5, pp. 728-731; 743-753.
- (d) Weiss, G., ed. 1980. Hazardous Chemicals Data Book. Noyes Data Corporation, Park Ridge, N.J.
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- (g) Stover, E. L. 1982. Removal of volatile organics from contaminated ground water. In Proceedings of the Second National Symposium on Aquifer Restoration and Groundwater Rehabilitation. National Water Well Association, Worthington, Ohio.
- (h) Palombo, D.A., and Jacobs, J.E. 1982. Monitoring chlorinated hydrocarbons in groundwater. In Management of Uncontrolled Hazardous Waste Sites, 1983.
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- (j) Chien, C.T., Peters, L.J., and Freed, V.E. 1979. A physical concept of soil-water equilibria for nonionic organic compounds. Science 206:831-832
- (k) Leo, A., Hansch, C., and Elkins, D. Partition 1971 coefficients and their uses. Chem. Rev. 71:525-616
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- (m) United States Environmental Protection Agency (USEPA). 1980. Treatability Manual. Volume I: Treatability Data. Office of Research and Development, Washington, D.C. July 1980, EPA 600/8-80-042a.
- (n) Weast, R.E. (ed). 1975-1976. Handbook of Chemistry and Physics. 56th Edition. CRC Press, Inc., Cleveland, Ohio. 2332 pages

the environment than PCBs. These factors are considered in modeling the transport of volatile organics via volatilization and via groundwater movement.

Volatilization is expected to be an important transport process for volatile organics. Residence times for these compounds in surface water or sandy topsoil are short due to volatilization. Thus, a substantial fraction of volatile organics potentially discharged from the plant (before 1981) already have evaporated and dispersed. Volatilization is also expected to be the principal reason why concentrations in shallow and near-surface soil/sediment samples collected at the site in areas where significant volatile organics were detected at depth, exhibited low concentrations. In fact, except in the wax ditch, where waxy residues are expected to dissolve and partially immobilize organic compounds, no significant concentrations of volatile organics were detected in materials directly exposed to air at the site. It should also be noted that volatile organics were not detected in South Pond water either. The water was analyzed for priority pollutants in partial fulfillment of the requirements for an application to discharge pond water as part of the proposed remediation. The analysis was reported on August 23, 1983 and was included in the documents submitted to the USEPA and Ohio EPA on December 20, 1983.

Transport via volatilization can be modeled using the classical two-resistance theory of transport across an interface (Thibodeaux 1979) to derive a volatilization rate, G . The

volatilization rate, G , is a function of a pressure gradient driving force which is the difference between the ambient air concentration of a particular compound and the compound's vapor pressure. Levels of exposure can then be derived by inputting G into various air pollution plume models. However, potential exposure via volatilization from the Minerva site is expected to be insignificant because, except for the wax ditch, there are no significant concentrations of volatile organics in materials in direct contact with air, and organics in the wax ditch are expected to be effectively immobilized in the waxy residues. Volatilization from the wax ditch will occur only extremely slowly if at all.

The other potentially major pathway for migration of volatile organics from the Minerva site is transport via groundwater. Groundwater transport involves two components: vertical percolation from contaminated soils and sediments and horizontal movement driven by groundwater flow. Because volatile organics do not adsorb readily on silicate soils, the fraction of such compounds that do not evaporate at the surface or become immobilized in waxy residues are likely to percolate vertically and enter groundwater. Since volatile organics are soluble in waxes, such as those present in the wax ditch and scattered throughout South Pond and the rubble pile, compounds that become associated with waxy residues should remain relatively immobile.

Vertical percolation is driven principally by water from precipitation. Volatile organics are transported either as

a dissolved solute in the water phase, or, in areas where volatile organics have saturated the ground, as a separate organic phase pushed ahead by percolating rainwater. In either case, the rate of transport is limited by the average yearly quantity of percolating precipitation (10 inches percolate of the 40 inches of rain that fall annually in the Minerva area).

Once percolating volatile organics reach groundwater, dissolved compounds will be driven horizontally by groundwater flow. Undissolved organics will continue to be driven vertically by gravity as well as being pushed horizontally by groundwater flow.

Since dissolved organics will be carried along with groundwater flow, receptors using groundwater downgradient of a source of volatile organics may potentially be exposed to these compounds. The rate of movement of volatile organics in groundwater will be a function of the properties of the soil matrix within which the groundwater moves as well as the properties of the compounds dissolved in the groundwater. The hydrogeologic characteristics of the site are detailed in the June 20, 1983 report. The most important soil matrix parameter is the permeability which, in turn, is a function of the chemical composition of the soil, the distribution of particle sizes within the soil matrix, and properties of the percolating solvent.

The transport of contaminants, which are dissolved in a percolating solvent, is generally slower than the rate of solvent movement because contaminants become distributed between

the stationary soil phase and mobile solvent phase due to sorption. However, because the soils in the Minerva area are coarse at depth and contain no appreciable organic components, sorption is expected to be insignificant for volatile organics in groundwater. At equilibrium, the concentration ratio between the fraction of contaminant adsorbed in the soil and the fraction of contaminant dissolved in the solvent is known as the partition coefficient, K . Estimated values for partition coefficients for compounds similar to the major components found in groundwater at the site (TCE, 1,1-dichloroethane, and trans-1,2-dichloroethene) migrating in typical matrices found at the Minerva site are presented in Table 10. Aqueous permeabilities are also presented for each matrix material. As can be seen in Table 10, the partition coefficient for the deep sands and gravels that groundwater traverses in this region is much less than one. As a consequence, volatile organics are expected to move in groundwater at close to the rate of groundwater flow. Two other important conclusions can be derived from this table. First, since partition coefficients for most of the soils and sediments at the site are on the order of unity, such materials may contain relatively low concentrations of volatile organics (as in South Pond sediments and rubble pile soils) and still represent potentially significant sources of groundwater contamination. Second, because sediment and soils exhibit partition coefficients on the order of unity, they are expected to become depleted relatively rapidly.

TABLE 10
AQUEOUS PERMEABILITIES AND ESTIMATED
VOLATILE-ORGANIC PARTITION COEFFICIENTS
FOR VARIOUS SOLID MATERIALS PRESENT
AT THE TRW MINERVA SITE

Material	k_{vo}	k_{1254}	Aqueous Permeability (cm/sec)
Pond sediments	1-10	10^4 - 10^5	$10^{-5}{}^a$
Clay	<1	10^2 - 10^3	10^{-6} - $10^{-8}{}^a$
Sandy loam topsoil	<1	10^3 - 10^4	$2.8 \times 10^{-3}{}^b$
Deep Sands and Gravels	<1	1 - 10^3	$8.5 \times 10^{-3}{}^b$
Wax	10-100	10^6	$<10^{-8}{}^c$

^aBased on typical values for such materials (Bear 1979)

^bDerived from a soil survey of Stark County Ohio (USDA 1971)

^cEstimated

Note: k_{vo} is the dimensionless ratio between the concentration of a volatile organic compound in water and soil material by weight at equilibrium. Values are derived by multiplying k_{1254} values by the ratio of the aqueous solubility of Aroclor 1254 and the solubility of particular volatile organic compounds. The ranges indicated will cover the predominant volatile organics found at the TRW site (1,1,1-trichloroethane, trichloroethene, 1,1-dichloroethane, and trans-1,2-dichloroethene).

k_{1254} are partition coefficients between water and soil materials for Aroclor 1254. Values were derived in the June 20, 1983 report.

The movement of volatile organics in groundwater at the Minerva site was modeled in two ways. If a potential localized source at the site could be adequately characterized, a rate of influx, Q , from the source and an initial concentration, C_0 , in the influx were derived for the source. This is because the concentration at any point downgradient of a source has been shown to be a strong function of these two parameters.¹ Because the original sources of TCE at the site have apparently been depleted, and TCE is the major volatile organic found in groundwater, the site was also modeled as a diffuse source where groundwater data was used to derive an average contaminant concentration in a vertical cross-sectional area under the site. In either case, the output from these calculations were used to derive loadings which could be combined with dilution factors typical of potential receptors to predict potential exposures. Receptors considered include the Minerva well, Sandy Creek, and hypothetical small volume wells which might be developed downgradient of the site in the future. Parameters used to model potential receptors were detailed in the June 20, 1983 report.

Before discussing the strength of potential sources at the site, an apparent discrepancy must be resolved. While the predominant volatile organic detected in soils, sediments, and waxes on the TRW site is TCA, almost no TCA has been detected in groundwater, and the principal compounds detected in ground-

¹See the discussion presented in the June 20, 1983 report.

water (TCE, 1,1-dichloroethane, and trans-1,2-dichloroethene) have only been detected as traces in soils and sediments and at low concentrations in waxes. This observation, in fact, supports the transport models developed in this report as follows.

Assuming that groundwater concentrations of TCE and TCA move at the rate of local groundwater flow, and considering the historical use of these compounds at TRW, TCE has apparently moved sufficiently to be detected at existing monitoring wells on the property while TCA apparently has not. Additionally, TCE percolation may have depleted TCE sources at the TRW site, accounting for its limited detection in soils and sediments. Since TCE use ceased in 1972 (when TCA use began) and groundwater at the site flows at 0.11 feet/day (as documented in the June 20, 1983 report), after 12 years, the leading edge of a potential TCA plume would be 500 feet downgradient from the point of infiltration.¹ Such a distance would also represent the peak of any potential TCE plume because TCE would no longer have been introduced to the site after 1972, and residual concentrations in soil and sediment would begin to be depleted at that point. In addition, because the most likely point of infiltration for compounds currently detected in groundwater is a small area in the South Pond or wax ditch, as discussed earlier,

¹Note that since TCE use began in 1957, the leading edge of the TCE plume is expected to be 1,000 feet downgradient of any potential source and not yet moved off the TRW property.

the leading edge of the TCA plume and the peak of the TCE plume would be expected to reside somewhere between wells 10 and 19 (500 feet downgradient of the suspected source). This is exactly what is observed. The concentration of TCE exhibited in well 19 is greater than in well 10 indicating the peak of the plume has passed well 10. Also, TCA is only now beginning to be detected at trace levels in well 10.

Based on the conclusions developed in the last paragraph, it is assumed that, because past TCE use was similar to current TCA use at the site, the characteristics of past TCE sources at the site correspond to characteristics of current TCA sources at the site. Similarly, the current distribution of TCE in groundwater is expected to mimic the potential future distribution of TCA in groundwater (assuming the site is not modified through remediation). Note that the source of the lesser chlorinated species is assumed to be degradation of TCA or TCE because there are no records of prior use of these materials at the TRW site. Therefore, current TCA concentrations in soil or sediment at the site (or potential future groundwater concentrations) should actually be compared with the combined total concentration of TCE, 1,1-dichloroethane, and trans-1,2-dichloroethene. Thus, exposure calculations from localized sources at the site are estimated based on TCA, and it is assumed that the combined total of TCE, 1,1-dichloroethane and trans-1,2-dichloroethene exposure would correspond to these calculations. Similarly, exposure calculations based on a diffuse groundwater

source that are derived from the combined total contributions of TCE, 1,1-dichloroethane, and trans-1,2-dichloroethene are assumed to mimic TCA calculations.

Based on principals developed in the above discussion, contributions of volatile organics to groundwater were calculated from data developed in this study. Such contributions were then combined with dilution factors derived for potential receptors in the June 20, 1983 report to estimate potential exposure.

The characteristics of potential volatile organic localized sources at the TRW site (including the wax ditch, South Pond, the rubble pile, and the "hot spot" in the rubble pile) are presented in Table 11. The potential contributions of TCA to groundwater were calculated based on the characteristics presented and are displayed in the last column of the table. The current distribution of TCE, 1,2-dichloroethene, and trans-1,2-dichloroethene in groundwater was also used to model the whole site as a diffuse source. To model the site as a diffuse source, the concentration of each compound detected in well 19 was assumed to represent the average of a plume front 90 feet deep (the thickness of the aquifer), 250 feet wide (the distance between well 18 and well 11 across the hypothesized plume), and traveling at 0.11 feet per day. A second plume was also assumed to be radiating from the rubble pile with an average concentration for each compound represented by that detected in well 13. In the latter case, the concentration in well 13 was adjusted by multiplying by the ratio of concentrations

TABLE 11

CHARACTERISTICS OF POTENTIAL LOCALIZED VOLATILE ORGANIC SOURCES
AT THE TRW MINERVA SITE AND CALCULATED "WORST-CASE" POTENTIAL
VOLATILE ORGANIC CONTRIBUTIONS TO GROUNDWATER

Potential Source	Average TCA Concentration in Source Matrix (ppm)	K ^a (dimensionless)	C _o ^b (ppm)	Surface Area ^c (ft ²)	(ft ³ Q ^c /day)	Loading ^d (lbs/day)
Wax ditch	17,000	50	340	9,000	0.26	0.0055
South Pond	13	5	3	70,000	1,200	0.22
Rubble pile	4 ^e	0.5	8	23,000	160	0.080
	20,000 ^f	50 ^g	400	1,000 ^h	7	<u>0.17</u>
Total						0.48

^aDerived specifically for 1,1,1-trichloroethane from the data presented in Table 10

^bDerived by multiplying the average concentrations in the source matrix by K for the source matrix

^cObtained from site models detailed in the June 20, 1983 report

^dDerived by multiplying C_o and Q for each source

^eAverage derived omitting the results of the samples in the "hot-spot" core

^fAverage of the "hot-spot" core samples

^gBecause such high concentrations still exist in this area of the rubble pile, such materials must be associated with waxes or they would have been depleted by this time

^hA conservative assumption is that the "hot spot" covers 1,000 ft²

in well 19 and well 10 to compensate for the fact that well 13 is not as far downgradient as well 19. This second plume was also assumed to be 90 feet deep and 250 feet wide. Contributions from each plume were then added. Results are displayed in Table 12. It should be noted, however, that a fair amount of uncertainty is associated with such diffuse source calculations because the distribution of volatile organics further downgradient than well 19 is unknown; there currently are no monitoring wells further downgradient than well 19.

Results of diffuse source and localized source modeling can be compared by looking at the total loading calculated for each model. Only total loading can be compared directly because localized source modeling considers the total contributions from all volatile organic compounds at any source¹ but is broken down by contributions from portions (individual localized sources) of the site while diffuse modeling considers contributions from the entire site simultaneously but is broken down by contributions from individual chemicals. Note that agreement between total predicted loadings from each model is excellent.

¹In localized source modeling, the total volatile organic contribution is considered because it is assumed that the TCA concentrations detected at the source have not yet degraded to generate the lesser chlorinated species. At the same time, the lesser chlorinated species detected in groundwater along with TCE are assumed to represent degradation products of TCE so that the sum of their contributions would represent the initial TCE concentrations in the plume.

TABLE 12

CONTRIBUTIONS OF VOLATILE ORGANICS TO GROUNDWATER FROM THE TRW SITE
BASED ON DIFFUSE SOURCE ESTIMATES

Compound	Contribution from Plume Passing Well 19 (lbs/day)	Contribution from Plume Passing Well 13 (lbs/day)	Combined Total Loading (lbs/day)
TCE	0.057	0.0075	0.065
1,1-Dichloroethane	0.057	0.084	0.14
trans-1,2-Dichloroethene	0.057	0.036	0.093
Total	0.17	0.13	0.30

Predicted loadings of volatile organics either from localized sources or diffuse sources can be used to derive potential exposure estimates. To accomplish this, each loading is divided by the daily flow of water at a particular receptor to account for dilution. Receptors considered include the Minerva well, Sandy Creek, and hypothetical small volume wells that might be placed downgradient of the TRW site in the future (no such wells currently exist). Flow characteristics for these receptors and assumptions used to derive dilution factors were detailed in the June 20, 1983 report. Predicted exposures to volatile organics at these receptors based on localized source calculations are presented in Table 13. Predicted exposure based on diffuse source calculations are presented in Table 14. The significance of these results is evaluated based on a review of the toxicity of the volatile organic compounds that have been detected at the TRW site. The toxicity of volatile organics is presented in the following section.

B. Toxicity Assessment

Toxicity data and water quality criteria for the six chlorinated hydrocarbons found in groundwater at Minerva are summarized in Appendix A. Criteria levels for four of the chemicals derived by EPA and the National Academy of Sciences (NAS) are tabulated in Table A.1. Corresponding criteria levels for the other two chemicals have not been established by EPA or NAS, but can be estimated from data on relative toxicity, as discussed in Appendix A. It should be emphasized that these criteria

TABLE 13

PREDICTED EXPOSURE TO VOLATILE ORGANICS DUE TO
PERCOLATION FROM LOCALIZED SOURCES AT THE TRW SITE

Source	Minerva Well ^a (ppb)	Sandy Creek ^a (ppb)	Personal Wells ^b (ppb)
Wax ditch	0.60	0.09	150
South Pond	24	3.6	5,000
Rubble pile	8.7	1.3	2,000
Hot spot	18	2.8	4,600
Total ^c	51	7.8	5,000

Note: All exposure values presented in the table represent the total concentration of volatile organics. Individual contributions from specific compounds can be derived from diffuse modeling results

^aValues are calculated assuming the volatile organic loadings for each source are diluted by the daily flow for the receptors indicated. Flow data for receptors was provided in the June 20, 1983 report.

^bValues for predicted exposure in small volume wells are calculated by assuming the potential plume will move 1,000 feet and disperse over that distance before being intercepted by a small volume well.

^cTotals are derived by inspection assuming superposition. Superposition is a complicated function that is not always additive.

TABLE 14

PREDICTED EXPOSURE TO SPECIFIC VOLATILE ORGANIC COMPOUNDS
DUE TO GROUNDWATER MOVEMENT OF A DIFFUSE SOURCE AT THE TRW SITE

Compound	Minerva Well ^a (ppb)	Sandy Creek ^a (ppb)	Personal Wells ^b (ppb)
TCE	7	0.96	520
1,1-Dichloroethane	18	2.4	1,300
trans-1,2-Dichloro- ethene	9	1.1	580
Total volatile organics	34	4.5	2,400

Note: Exposure values presented in the table represent the total contribution from all potential localized sources at the site for each specific compound listed.

^aValues are calculated assuming the volatile organic loadings for each source are diluted by the daily flow for the receptors indicated. Flow data for receptors was provided in the June 20, 1983 report.

^bValues for predicted exposure in small volume wells are calculated by assuming the potential plume will move 1,000 feet and disperse over that distance before being intercepted by a small volume well.

are not presented as "safe" or "acceptable" levels. They are concentrations which bear a defined relationship to doses that have been shown to produce adverse effects, and hence, can be used to judge the significance of concentrations that are found in water.

It is clear from Table A.1 and the discussion in the Appendix that there is a wide range of possible numbers that can be used as water quality criteria for each chemical. Table 15 tabulates criteria levels which we consider appropriate for each of the six chemicals with notes on their basis and limitations. Each of these criteria levels should be interpreted in terms of the qualifications noted in the right hand column of Table 15. For comparison, a criteria level of PCBs based on CAG's unit risk calculation would be about 0.16 ppb, two orders of magnitude below that for TCE and three orders of magnitude below that for TCA.

C. Risk Evaluation

Potential human health risks attendant to volatile organic concentrations as they presently exist at the TRW site, or as they might exist in the future, are evaluated by combining results of exposure and toxicity assessments. It should be emphasized, however, that there is no indication that population exposures are occurring at present. Estimates of the time required for volatile organics detected at the TRW site to reach potential receptors were derived from the linear velocity of local groundwater (0.11 feet/day) and distances to potential

TABLE 15

CRITERIA LEVELS FOR SIX CHLORINATED HYDROCARBONS
IN GROUNDWATER USED FOR DRINKING WATER SUPPLIES

Chemical	Criterion Level (ppb)	Basis for Criterion Level and Comments
Trichloroethene (TCE)	18	Lower limit on level that might lead to 10^{-5} excess cancer risk after lifetime ingestion of 2 liter/day (CAG calculation)
1,1-Dichloroethene (1,1,-DCE)	2.4	Lower limit on level that might lead to 10^{-5} excess cancer risk after lifetime ingestion of 2 liter/day (CAG calculation)
trans-1,2-Dichloro- ethene (1,2-DCE)	6	Estimate based on data indicating that 1,2-DCE is intermediate in toxicity between TCE and 1,1-DCE; this estimate incorporates the conservative assumption that 1,2-DCE would also be carcinogenic if tested, and that its potency would be intermediate
1,1,1-Trichloroethane (TCA)	217	Lower limit on level that might lead to 10^{-5} excess cancer risk after lifetime ingestion of 2 liter/day (CAG calculation); the basis for this estimate is very questionable because there is no conclusive evidence for carcinogenicity. A criterion level based on non-carcinogenic effects would be EPA's SAADI of 1,000 ppb.

TABLE 15 (continued)

Chemical	Criterion Level (ppb)	Basis for Criterion Level and Comments
1,1,-Dichloroethane (1,1-DCA)	500	Estimate based on data indicating that 1,1-DCA is approximately twice as toxic as 1,1,1-TCA; this estimate is based on non-carcinogenic toxic effects and should therefore be based on the SAADI for TCA
1,2-Dichloroethane (1,2-DCA)	5.0	Lower limit on level that might lead to 10^{-5} excess cancer risk after lifetime ingestion of 2 liter/day (CAG calculation)

receptors presented in the June 20, 1983 report. Three receptor groups were considered: users of the Minerva wells, users of Sandy Creek, and potential users of small-volume private wells that might in the future be developed downgradient of the site. Based on these estimates, volatile organics will not reach Sandy Creek for another 5 years¹ and will not reach the Minerva wells for another 75 years. Private wells do not currently exist downgradient of the TRW property.

Estimated exposures to specific volatile organics presented in the exposure assessment section can be compared directly to water quality criteria reported in the toxicity assessment. Potential future exposure to TCE, 1,1-dichloroethane, and trans-1,2-dichloroethene are presented in Table 14. Water quality criteria, derived from a variety of sources, are presented in Table 15 for these three compounds and three other compounds which have also been detected at the TRW site. Inspection of these two tables indicates that if conditions at the site are not intentionally altered (i.e., by remediation), potential exposure to TCE, 1,1-dichloroethane, and trans-1,2-dichloroethene would exceed derived criteria for hypothetical users who might develop private wells downgradient of the site. More important, future exposures to users of the Minerva wells might exceed derived criteria for trans-1,2-dichloroethene. Additionally,

¹Due to the limit of precision generally associated with these estimates, however, a 5-year value may indicate that the leading edge of the TCE plume has already reached Sandy Creek or will do so in the near future.

although the derived criteria for TCE is not exceeded by the future exposure estimated for the Minerva wells, the difference between the estimated TCE exposure and derived criteria is not considered significant. It should be noted that none of the derived criteria are exceeded by estimated exposures to users of Sandy Creek, although differences between derived criteria and estimated exposures for TCE and trans-1,2-dichloroethene for these receptors are considered insignificant. Since the estimated future exposures presented in Table 14 are derived from groundwater concentrations of volatile organics, the above comparison indicates that the current concentrations of volatile organics detected in groundwater at the TRW site should be addressed as part of an overall site remediation plan.

Estimated future exposures to various potential receptors due to the current concentrations of volatile organics in soils and sediments at the TRW site are presented in Table 13. These may also be compared with derived criteria presented in Table 15, although the comparison is not as straightforward as in the case above. The estimated exposures presented in Table 13 are derived from soil and sediment concentrations of TCA found at the site. Thus, assuming the potential future exposures presented in Table 13 represent solely TCA, the derived criterion (from Table 15) would be exceeded for potential users of hypothetical private wells. At the same time, future estimated exposures to users of the Minerva well or Sandy Creek are significantly below the criterion for TCA. However, TCA will

presumably degrade with time (as TCE apparently has) so that one or several of the lesser chlorinated compounds listed in Table 15 also would be expected to contribute to a potential groundwater plume resulting from the migration of TCA. Therefore, one or several of the dichlorinated species presented in Table 15 may end up representing a substantial fraction of the estimated total exposure presented in Table 13. Since derived criteria for some of these compounds are exceeded by estimated total exposures presented for users of the Minerva well and Sandy Creek in Table 13, contributions from localized sources at the TRW site should also be addressed in an overall site remediation plan.

Based on the above discussion, both the potential for migration of volatile organics from localized sources at the TRW site (the wax ditch, South Pond, and the rubble pile) and the continued migration of volatile organics detected in groundwater must be addressed as part of an overall site remediation plan. The proposed site remediation plan presented in the June 20, 1983 report (and designed to address the independent PCB problem discovered earlier at the site) was therefore evaluated to determine whether the problem of volatile organics would be adequately addressed by this plan. According to the proposed plan, all of the wax ditch and South Pond sediments will be excavated and encapsulated in an on-site secure cell. Such excavations will effectively remove volatile organics (principally TCA) from these areas along with residual PCBs.

According to the proposed plan, however, the rubble pile will not be entirely excavated but will be capped with local clay. Since the proposed excavation in the rubble pile does not include the volatile organic "hot-spot" detected in this study, it is uncertain whether capping will be sufficient to preclude significant migration of volatile organics from the rubble pile. Additional excavation is therefore recommended in the rubble pile.

The applicability of the proposed on-site encapsulation toward immobilizing volatile organics excavated as part of proposed remediation was also investigated. The predominant volatile organic present in the soils and sediments that will be excavated under the proposed plan is TCA. Based on the concentrations of TCA detected in these materials and the estimated partition coefficient presented for TCA in Table 11, it is unlikely that soils or sediments are saturated with volatile organics anywhere on the TRW site. Thus, coupled with the fact that infiltration into and (subsequently) out of the proposed encapsulation cell was estimated to be essentially zero,¹ the proposed encapsulation of excavated material will effectively immobilize volatile organics present in localized sources at the TRW site. Therefore, with minor modifications, the proposed remediation plan will effectively eliminate localized sources of volatile organics at the TRW site.

¹"Preliminary Engineering Design for the Minerva Ohio Site." Prepared by O'Brien and Gere (1983) for TRW and submitted to the U.S. and Ohio EPAs on December 20, 1983.

The proposed remediation plan presented in the June 20, 1983 report does not address the problem of continued migration of volatile organics already present in groundwater. Since the original plan was designed to address PCBs, and PCB concentrations detected in groundwater are minimal, the problem of preventing further migration of materials already present in groundwater was not considered. Therefore, a method for preventing further migration of volatile organics already present in groundwater should be added to an overall site remediation plan.

There is one additional mechanism by which volatile organics at the TRW site might potentially affect human health or the environment. If present in sufficient concentrations, volatile organics may affect the transport of PCBs in the environment. However, concentrations of volatile organics detected in soils, sediments, and groundwater at the TRW site are so low that, except for very localized and isolated cases (which would not alter the general results of the earlier exposure calculations) the movement of PCBs and volatile organics at the TRW site may be treated independently.

IV. RECOMMENDATIONS

Based on the risk assessment provided in Section III, both the potential for migration of volatile organics from localized sources (the wax ditch, South Pond, and the rubble pile) and continued migration of volatile organics already present in groundwater must be addressed as part of an overall site remediation plan. The proposed remediation plan presented in the June 20, 1983 report was also evaluated and found to be insufficient to adequately address the latter of the above concerns. However, the plan would (with minor modifications) eliminate localized sources of volatile organics. A series of recommended modifications to the proposed remediation plan presented in the June 20, 1983 report (which are designed to fully address potential problems associated with volatile organics) is, therefore, presented in the following paragraphs.

It should be noted that the recommended modifications to the proposed remediation plan are designed to fit into the anticipated schedule for remediation. Provided that each step in the program is completed in a timely fashion, all remediation can be executed within the time frame initially envisioned with no prolongation.

To insure that the migration of volatile organics in the rubble pile will be prevented, it is recommended that additional sections of the rubble pile be included in the overall excavation

at the site. Preparation for this modification is expected to be minimal and involves:

- Determining the new boundaries of the excavation from the available data
- Calculating the total volume of soil to be removed
- Modifying the encapsulating cell construction plan, if necessary, to ensure that the additional material can be incorporated.

Provided that these calculations are completed before the preparation of bid documents for the site excavation and construction of the secure cell, incorporating this modification should have no measurable impact on the timing of the proposed remediation.

It is recommended that a groundwater withdrawal and treatment system be added to the site remediation plan to preclude the migration of volatile organics already present in groundwater. Preparation for this modification is complicated because additional studies are needed and the installation of a water treatment facility will require submittal and approval of additional permit applications. If the studies are initiated promptly, however, and all components of the project are well coordinated, delay of the overall remediation plan can be avoided.

To effectively design a well withdrawal field, a three-dimensional profile of the distribution of volatile organics will have to be developed, a pumping test will have to be performed, and water quality parameters will have to be better defined. As a consequence, several additional monitoring wells will be installed to obtain the required data and at least

two of the wells will be designed for multilevel sampling over the entire depth of the aquifer. Wells will be installed in phases to maximize the information gained and minimize the cost. A new groundwater monitoring workplan, which will address these considerations, is currently in preparation.

Once sufficient data have been collected from the new monitoring wells, a study will be initiated to determine the optimum placement of groundwater withdrawal wells, and the withdrawal rate will be calculated. The well withdrawal field will be designed to alter local groundwater flow and preclude the migration of volatile organics beyond the TRW property. In time, much of the volatile organic concentrations present in groundwater also will be removed as pumping continues.

Based on the flow data developed for the well withdrawal field and the water quality data developed from water analyses, a water treatment facility will be designed to remove volatile organics from groundwater and generate an output stream suitable for discharge to local surface waters. At this time it appears that the most applicable treatment technology is air stripping. Engineering designs for an air stripper will be developed and applications for appropriate installation, operation, discharge and emission permits will be submitted to the various regulatory agencies as required. Upon approval, bid documents for the construction of the withdrawal well field and air stripper will then be prepared, and this modification will be incorporated into the overall site remediation plan.

In summary, though modifications to the proposed remediation are recommended, it is not necessary to delay the start of the proposed program. Preparatory work is proceeding and will ultimately include:

- Completion of a new groundwater monitoring workplan
- Installation of additional monitoring wells
- Development of additional groundwater data
- Design of a well withdrawal field and groundwater treatment system
- Preparation and submittal of appropriate applications for the construction and operation of the proposed groundwater treatment system
- Modification of the engineering designs for the overall site remediation plan to incorporate new excavation in the rubble pile and installation of a groundwater withdrawal and treatment system.

Execution of the overall site remediation plan can then proceed as soon as approval is granted.

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APPENDIX

TOXICITY DATA AND WATER QUALITY CRITERIA FOR THE CHLORINATED HYDROCARBONS FOUND IN GROUNDWATER AT MINERVA

Six chlorinated hydrocarbons--trichloroethene (TCE), 1,1-dichloroethane (1,1-DCE), trans-1,2-dichloroethene (1,2-DCE), 1,1,1-trichloroethane (TCA), 1,1-dichloroethane (1,1-DCA) and 1,2-dichloroethane (1,2-DCA)--have been found in the groundwater at the TRW manufacturing facility in Minerva, Ohio. Of these six compounds, there is some evidence that four--TCE, 1,1-DCE, TCA and 1,2-DCA--are carcinogenic in animals and hence potentially carcinogenic to humans. Recently, the EPA has set ambient water quality criteria for three of the four compounds--TCE, 1,1-DCE and 1,2-DCA, based on their carcinogenic potential USEPA 1980a,b,c. An ambient water quality criterion has also been set for TCA but is based on toxic effects other than carcinogenicity (the evidence that TCA is carcinogenic is especially weak and inconclusive) (USEPA 1980a). The other two compounds--1,2-DCE and 1,1-DCA--have no ambient water criteria because EPA found insufficient toxicity information (1980a,b).

In the absence of adequate data on these two compounds to establish firm water quality criteria, approximate criteria can be developed based on relative toxicity.

1,2-DCE is structurally similar to TCE and 1,1-DCE. Comparison of the hepatotoxicity of TCE and 1,2-DCE suggests that 1,2-DCE is more potent. Kylin et al. (1976, as reported by

USEPA 1980c) reported that long term inhalation exposure to 3,150 ppm TCE failed to produce more than a low incidence of fatty infiltration of the liver of experimental animals while Freundt et al. (1977) found that many rats exposed to an airborne concentration of 200 ppm 1,2-DCE, 7 hours per day, 5 days per week for 8-16 weeks had slight to severe fat accumulation in their livers. Jenkins et al. (1972, as reported by USEPA 1980b) compared the hepatotoxicities of 1,1-DCE and 1,2-DCE in the same study. They reported that 1,1-DCE was a more potent hepatotoxin than was 1,2-DCE. These results suggest that an appropriate water quality criterion for 1,2-DCE would be somewhere between those for TCE and 1,1-DCE.

A comparison of the toxicity of 1,1-DCA to that of TCA can be made based on results from National Institute of Cancer bioassays for carcinogenesis (NCI 1977, 1978) that were done on both compounds. Both compounds increased the mortality of male and female rats compared to control animals over the 2-year study. The 50% mortality level in treated groups of male rats occurred at approximately 50 and 60 weeks for TCA and 1,1-DCA, respectively. The 50% mortality in the respective control groups occurred at approximately 70 and 80 weeks. TCA and 1,1-DCA shorten the time until the 50% mortality levels were reached for the female rats from about 85 weeks for control groups to about 55 and 70 weeks for the respective treated groups. The dose levels of 1,1-DCA given to the rats were

about half of the dose levels given to TCA treated rats. Thus, 1,1-DCA appears to be approximately twice as toxic as TCA.

Table A.1 summarizes water quality criteria for the four compounds for which EPA has recommended criteria. For reasons stated above, appropriate water quality criteria for 1,2-DCE and 1,1-DCA could be estimated by interpolation.

TABLE A.1
WATER QUALITY CRITERIA FOR FOUR
CHLORINATED HYDROCARBONS

Basis for Criterion and Agency	Criterion Concentration (µg/liter) ^e			
	TCE	1,1-DCE	1,1,1-TCA	1,2-DCA
Criteria based on carcinogenic effects (10^{-5} risk level) ^f				
EPA: Ambient Water Quality Criteria ^a	17	0.33		9.4
EPA: Carcinogen Assessment Group "unit risk" ^b	18	2.4	217 ^g	5.0
National Academy of Sciences, Safe Drinking Water Committee ^c	45		168 ^g	7.0
Criteria based on noncarcinogenic effects (safety factor approach) ^h				
EPA: Acceptable Daily Intake (ADI) ^a		600	18,400	
EPA: Suggested Adjusted Acceptable Daily Intake ^d	260	350	1,000	260

^a Ambient Water Quality Criteria Documents (published by EPA for each chemical (USEPA 1980a,b,c))

^b Tabulated by EPA in a number of documents, most recently in USEPA (1983)

^c Drinking Water and Health, Vols. 1-4 (National Academy Press, Washington, DC (NAS 1977, 1980a,b 1982))

^d National Primary USEPA Drinking Water Regulations; Volatile Synthetic Organic Chemicals (1984)

^e Based on assumed consumption of 2 liters drinking water per day

^f Estimate of upper limit on concentration in drinking water that might, under conservative assumptions, give rise to a lifetime excess risk of cancer of 1 in 100,000, assuming lifetime exposure

^g Based on an experimental study that is now regarded as of questionable reliability

^h Concentration providing an ample margin of safety below a level that causes no observable adverse effects in animals

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